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HYBRID MAIZE BREEDING AND SEED PRODUCTION

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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HYBRID MAIZE BREEDING AND SEED PRODUCTION

FRONTISPIECE. - *Hybrid maize is revolutionizing agriculture in many sections of the world. This single cross, R61 × 187-2, borders performance trials of newly-developed hybrids on the University of Illinois Agronomy Farm.*

FAO Agricultural Development Paper No. 62

Hybrid Maize Breeding and Seed Production

by
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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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FOREWORD

Hybrid maize (corn) and modern production practices revolutionized American agriculture. Hybrid maize promises to be an increasingly important crop in many other sections of the world. This includes areas where little or no maize is now being grown.

Maize breeding and seed production programs are being conducted in many countries. The present national hybrid maize programs in European and Mediterranean countries are supplemented in various ways by the Food and Agriculture Organization of the United Nations (FAO).

FAO has contributed to the co-operative hybrid maize programs by:

1. conducting an introductory course on hybrid maize breeding;
2. providing seed and sponsoring uniform tests of hybrids;
3. compiling and publishing the results of performance tests, fertilizer trials, and population density studies;
4. sponsoring annual conferences of maize workers;
5. encouraging the free interchange of breeding materials, research data, and improved techniques;
6. supplying advice on improved breeding and production procedures.

The primary purpose of this volume is to present the principles and procedures involved in hybrid maize breeding and seed production. Another object has been to bring together widely scattered literature references.

This paper evolved from a course in the breeding and genetics of maize that was taught by the author during the past 10 years at the University of Illinois to advanced undergraduates, graduate students, and professional maize workers from many countries.

The author, Dr. R. W. Jugenheimer, is professor of plant genetics in the College of Agriculture of the University of Illinois at Urbana, Illinois, U.S.A. He is in charge of maize breeding in the Department of Agronomy at that institution. Dr. Jugenheimer served with FAO as consultant on hybrid maize during the period June 1952 to June 1953, and after his return to the University of Illinois, he prepared the manuscript which is published as an agricultural development paper under a contractual arrangement with FAO. Much of the material was prepared initially

in connection with Dr. Jugenheimer's teaching duties at the University of Illinois and FAO is grateful to that institution for making the material, as well as Dr. Jugenheimer's services, available to FAO.

The author is grateful to Merle T. Jenkins, formerly Principal Agronomist in Charge of Corn Investigations, United States Department of Agriculture, and Research Director, Agricultural Alumni Association, Lafayette, Indiana; E. H. Rinke, formerly Consultant to FAO on Hybrid Maize, and Professor of Genetics, University of Minnesota; and H. K. Hayes, Professor Emeritus of Agronomy and Plant Genetics, University of Minnesota, for reading and commenting on the manuscript. Special acknowledgement is due to L. B. Howard, M. B. Russell, W. L. Burlison, C. M. Woodworth, and other associates of the author at the University of Illinois. Thanks are due to Dr. and Mrs. G. H. Dungan for preparing the subject matter index. Appreciation is expressed to the author's wife, Mabel H. Jugenheimer, and to secretaries and assistants for their aid.

Pertinent additions to the list of references, and constructive suggestions for the improvement of the book may be sent to the author at the University of Illinois, Urbana, Illinois, U.S.A.

The following contributed to the data summarized in Tables I to V, inclusive in the Appendix, and have kindly given permission to publish the data: R. A. Blanchard, A. M. Brunson, R. S. Davidson, F. F. Dicke, H. K. Hayes, E. T. Hibbs, P. E. Hoppe, L. L. Huber, M. T. Jenkins, L. M. Josephson, R. W. Jugenheimer, C. H. Kingsolver, L. E. Livingston, J. H. Lonnquist, Catherine Madsen, N. P. Neal, C. R. Neiswander, L. H. Patch, E. L. Pinnell, E. H. Rinke, Alice L. Robert, E. C. Rossman, Morris Schlossberg, D. B. Shank, F. W. Slife, G. F. Sprague, G. H. Stringfield, L. A. Tatum, A. J. Ullstrup, A. M. Vance, E. V. Walter, Wm. Wiidakas, and M. S. Zuber. The chemical analyses in Table V were provided by the staff of the Northern Utilization Research Branch of the United States Department of Agriculture, Peoria, Illinois (formerly Northern Regional Laboratory), and are published (Earle and Curtis, 1956).

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PART I

Introduction and General Topics

1. MAIZE IN WORLD AGRICULTURE

The Food and Agriculture Organization of the United Nations has pointed out that: "Only a third of the world's people get enough and the right kind of food for health and high energy. Half of the world's population lives at low nutrition levels. Starvation is not uncommon. Disease, early death, much infant mortality, low work-power, social tensions, economic strains, all reflect these conditions."

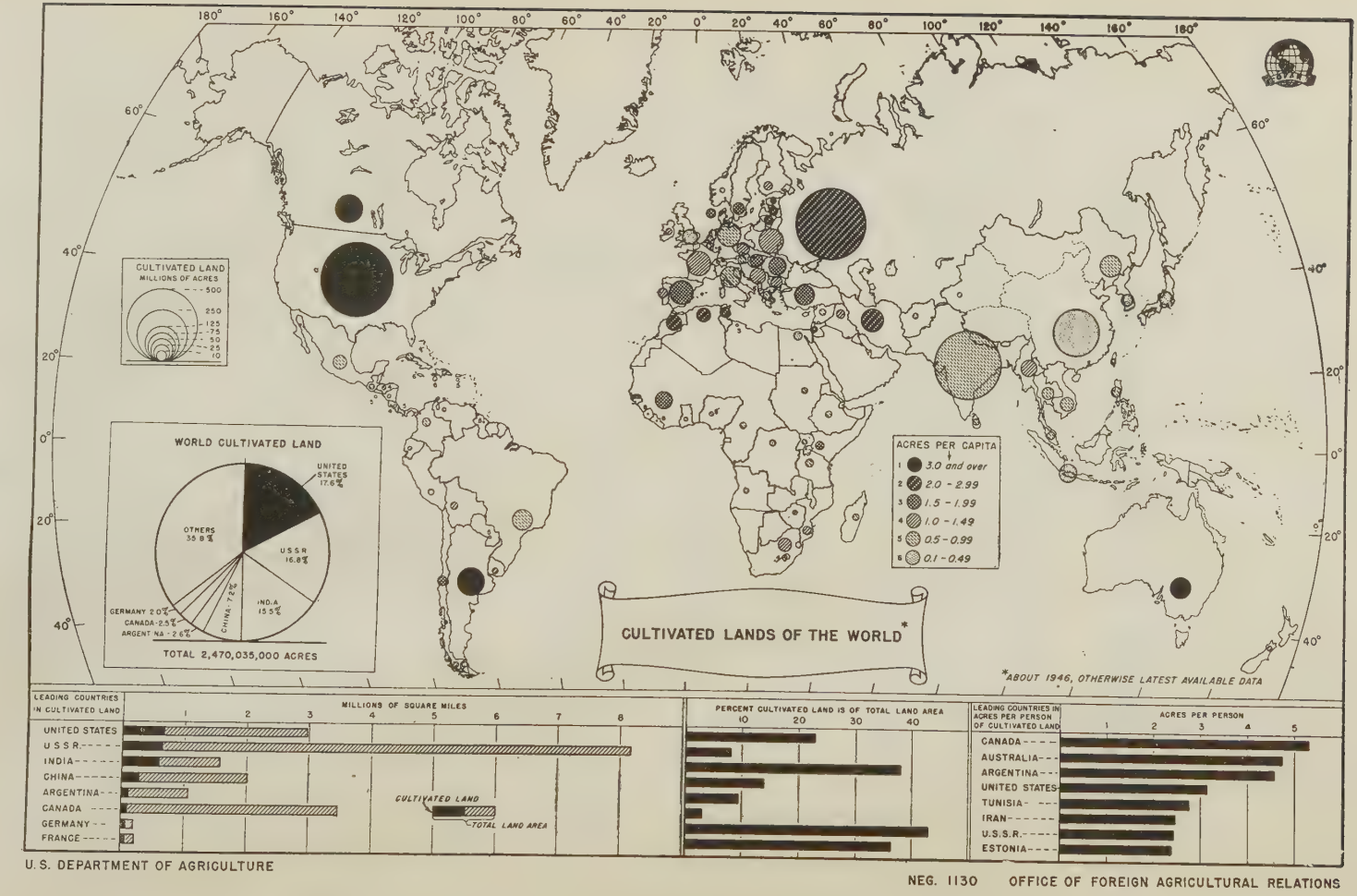
Land Areas of the World

FAO (1956) estimated that nearly 14 thousand million hectares in the world were utilized as follows:

Use of land	*Million hectares*
Arable, including fallow and orchards	1,352
Permanent meadows and pastures	2,358
Forests and woodlands	3,949
Unused and built-on areas	5,844

Most of the better crop land in the world is now being farmed. Some additional acreage can be added by costly conservation, reclamation, and irrigation projects. Increasing food and feed production, however, must come primarily from the land now being farmed. Countries with large areas of land include U.S.S.R., Canada, United States, China, India, Argentina, Australia, and Brazil (Figure 1). High percentages of the available land are being cultivated in Germany, India, France, United States, and China. Leading countries in acres per person of cultivated land include Canada, Australia, Argentina, United States, Tunisia, Iran, U.S.S.R., and Estonia.

This vital area of land is feeding a world population of approximately 27,000 million persons. World population, however, is increasing at the rate of about 25 million a year. Every minute of every day, about 50 persons are being added to the population of the world. Additional hungry people appearing at the table each day amount to approxi-



U. S. DEPARTMENT OF AGRICULTURE

NEG. 1130 OFFICE OF FOREIGN AGRICULTURAL RELATIONS

FIGURE 1. - *Most of the better cropland of the world is now being farmed.*

(Courtesy, United States Department of Agriculture)

mately 72,000 persons, which is equivalent to a city like Cambridge, England.

The countries of China, India, U.S.S.R. and the United States have high total populations (Figure 2). The United Kingdom, Japan, Italy, Germany, India, China, and France have high numbers of persons per square mile.

Maize Growing Areas of the World

Excluding the U.S.S.R., world maize production in 1954 totaled approximately 5.5 billion bushels (137,300,000 metric tons) on nearly 215 millions acres (86,900,000 hectares). Area, yield, and production of maize in specified countries are reported in Table 1, and shown in Figure 3. These data were obtained from the *Yearbook of Food and Agricultural Statistics* (Volume 9, Part 1) published by FAO in 1956. North America grows almost half of the maize acreage of the world. Other maize growing areas, in order of hectares grown, are the Far East, Latin America, Europe, Africa, U.S.S.R., the Near East, and Oceania (FAO, 1956a). Acreage of maize appears to be increasing in Asia and Africa, but decreasing in North America, Europe, South America, U.S.S.R., and Oceania.

The 10 leading countries in hectares planted to maize during the five-year period, 1934-1938, were the United States, China, Argentina, U.S.S.R., Brazil, Romania, Mexico, India, Yugoslavia, and Union of South Africa. During a later five-year period, 1948-52, the 10 leading maize growing countries, excluding the U.S.S.R., were the United States, China, Brazil, Mexico, India, Union of South Africa, Yugoslavia, Indonesia, Argentina, and Hungary.

Although the United States grows much more maize than any other country, it ranked below many others in yield per hectare as an average of 1934-1938. The countries with the highest yield per hectare during this period were Bolivia, Switzerland, New Zealand, Germany, Austria, Canada, Egypt, New Caledonia, Mauritius, and Czechoslovakia. During a more recent five-year period, 1948-1952, Belgium produced the highest yield per hectare, followed by New Zealand, Netherlands, Switzerland, Canada, United States, Hungary, Czechoslovakia, Egypt, and Austria.

The following 10 countries in that order had the highest total maize production during the five-year period, 1934-1938, United States, China, Argentina, Brazil, Yugoslavia, U.S.S.R., Romania, Italy, Hungary, and India. More recently, 1948-1952, the United States, China, Brazil, Mexico, Yugoslavia, Hungary, Argentina, Union of South Africa, Italy, and India, led in maize production.

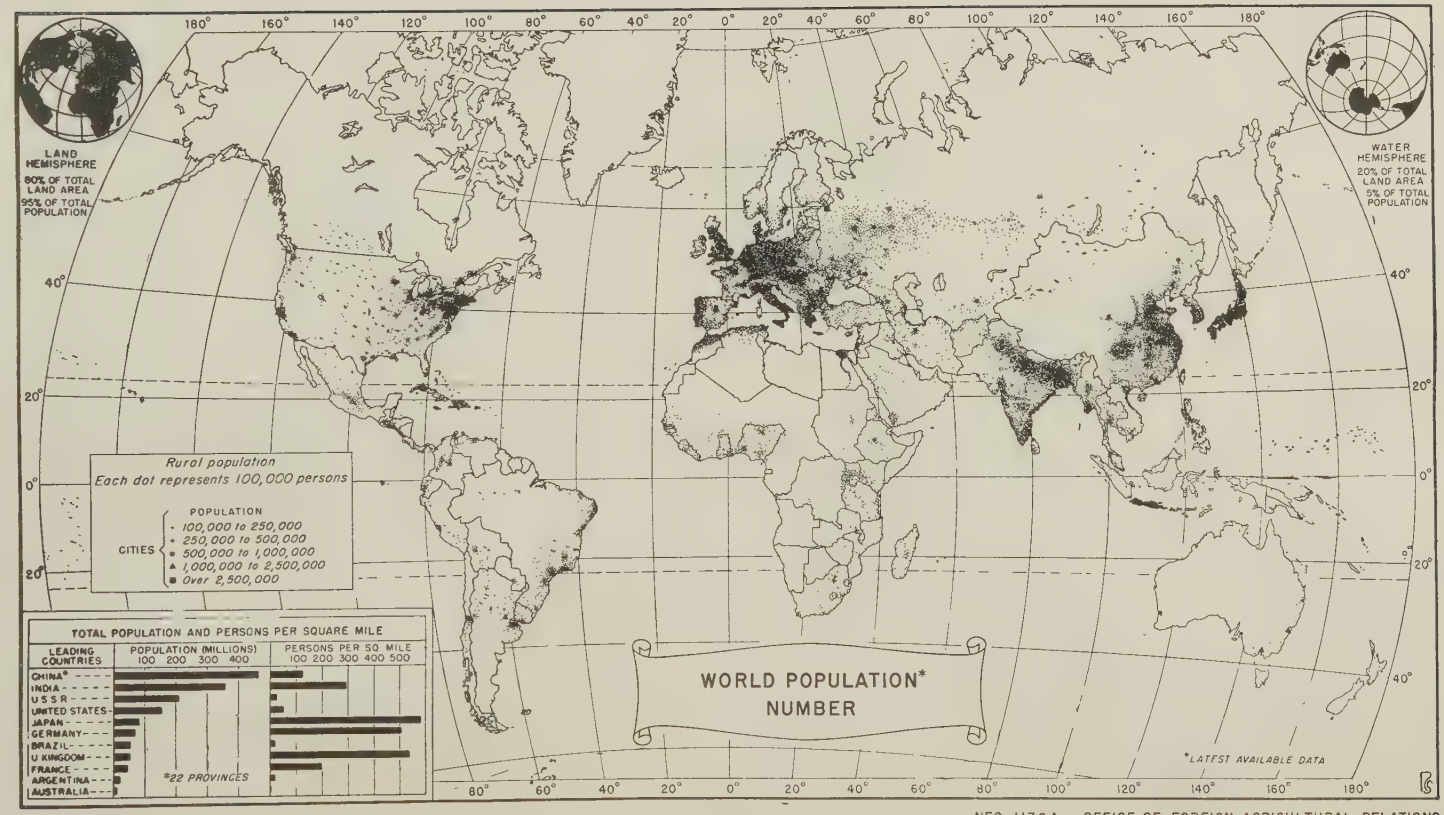


FIGURE 2. - *World population is increasing at the rate of about 25 million people a year.*

(Courtesy, Foreign Agriculture)

TABLE 1. — AREA, YIELD, AND PRODUCTION OF MAIZE IN SPECIFIED COUNTRIES

Continent and country	Area				Yield				Production			
	1934-38	1948-52	1953	1954	1934-38	1948-52	1953	1954	1934-38	1948-52	1953	1954
EUROPE	..... 1 000 hectares				..... 100 kg/hectare				..... 1 000 metric tons			
Albania	93	...	...	...	14.3	...	...	...	134	...	...	...
Austria	66	58	58	58	25.5	20.5	25.9	25.8	170	120	151	149
Belgium	...	1	2	2	...	41.2	50.7	47.9	—	3	12	11
Bulgaria	811	...	...	...	11.3	...	...	...	913	...	...	...
Czechoslovakia												
Grown alone	82	[1] 14	...	...	21.1	[1] 21.2	...	...	173	[1] *239	...	...
With other crops	33	[2] 31	...	...	15.6	[2] 17.5	...	...	52	[2] 55	...	...
France	342	324	375	411	15.8	13.8	21.4	23.3	541	447	803	955
Germany	32	...	...	...	28.4	...	...	...	91	...	...	...
Eastern	(15)	[2] 4	...	...	(25.9)	...	...	...	(40)	...	...	...
Western	(17)	9	7	7	(30.0)	...	...	...	(51)	20	19	20
Greece	256	[2] 243	269	262	9.6	9.3	11.5	9.7	246	225	309	255
Hungary	1 156	[2] 1 329	...	...	19 9	[2] 21.5	...	...	2 306	[2] 2 862	...	...
Italy	[3] 1 458	1 253	1 272	1 274	[3] 20.3	18.4	25 3	23.2	[3] 2 960	2 306	3 213	2 914
Liechtenstein	...	—	—	...	...	...	35 0	...	...	[4] 1	1	...
Netherlands	[5] 2	8	10	9	15.0	33.0	39.2	32.9	3	26	40	29
Poland	15	...	...	...	14.3	...	...	...	22	...	...	...
Portugal	410	491	475	486	7 2	8.0	7.4	7.9	293	393	350	386
Romania	*3 879	...	...	...	*10.4	...	...	...	*4 032	...	...	...
Spain	[6] 435	356	365	369	[6] 16 3	14 6	19.4	20.5	[6] 709	520	707	757
Switzerland	1	2	1	1	28 9	32 2	...	...	2	6	4	4
Yugoslavia	2 655	[7] 2 293	[7] 2 407	[7] 2 460	18.0	13.4	...	...	4 691	[7] 3 078	[7] 3 840	[7] 3 004
Total	***11 700***	***11 000***	***11 500***	***11 700***	***14.8***	***13.2***	***14.4***	***12.5***	***17 400***	***14 600***	***16 600***	***14 600***
U.S.S.R.	4 348	...	...	...	10.7	...	...	...	4 648	...	...	...
NORTH and CENTRAL AMERICA												
British Honduras	...	6	8	8	...	[4] 8.2	...	...	...	[4] 4	8	5
British West Indies												
Barbados	...	1	...	...	...	8.0	...	...	...	1	...	..
Jamaica	...	17	20	17	...	8.9	7.0	7.0	...	15	14	12

For notes, see end of Table 1, page 11.

TABLE 1. — AREA, YIELD, AND PRODUCTION OF MAIZE IN SPECIFIED COUNTRIES (*continued*)

Continent and country	Area				Yield				Production			
	1934-38	1948-52	1953	1954	1934-38	1948-52	1953	1954	1934-38	1948-52	1953	1954
	..... *1 000 hectares*				..... *100 kg/hectare*				..... *1 000 metric tons*			
NORTH and CENTRAL AMERICA (*concluded*)												
Canada	68	120	146	169	25.3	32.0	36.3	33.5	172	384	530	567
Costa Rica	24	[4] 58	75	72	5.7	[4] 13.2	11.7	...	14	[4] 65	80	...
Cuba	...	[2] 180	...	...	...	...	...	...	...	[4] 223	251	...
Dominican Republic	...	[4] 67	65	...	...	[4] 13.5	12.7	...	[8] 136	84	82	92
El Salvador	138	[9] 193	185	177	10.7	[1] 10.9	9.8	9.9	147	[9] 213	181	175
Guatemala	240	[4] 411	483	520	9.9	[4] 10.3	8.5	7.1	237	[4] 425	413	369
Haiti	[10] 3	[2] 120	...	...	[10] 19.8	[2] 7.9	...	...	[10] 5	[1] 98	...	...
Honduras	[10] 165	[4] 170	304	281	[10] 10.5	[4] 10.2	6.3	6.3	[10] 174	[4] 174	191	176
Mexico	2 976	4 107	4 863	4 400	5.6	7.5	7.6	...	1 665	3 097	3 720	*4 000
Nicaragua	38	102	136	...	9.2	9.8	10.2	...	35	100	139	...
Panama	...	[9] 63	86	86	...	[9] 9.6	9.0	8.8	...	51	77	76
Puerto Rico	[11] 28	21	12	...	[11] 7.2	8.9	9.6	...	[11] 20	18	12	...
United States [12]	37 831	33 510	32 620	32 524	14.0	24.4	24.9	23.5	53 066	81 690	81 092	76 463
Total	***41 900***	***39 300***	***39 300***	***38 700***	***13.3***	***22.0***	***22.1***	***21.3***	***55 900***	***86 650***	***86 900***	***82 400***
SOUTH AMERICA												
Argentina	4 362	1 696	2 414	1 863	18.1	14.8	18.4	13.7	7 892	2 509	4 450	2 546
Bolivia	[5] 27	[2] 116	116	...	[5] 30.0	[2] 11.9	11.9	...	[5] 81	[2] 138	138	...
Brazil	4 092	4 786	5 528	*4 698	13.9	12.4	12.3	...	5 677	5 916	6 789	*6 096
British Guiana	1	[9] 1	...	...	...	[9] 9.2	...	...	...	[9] 1	1	...
Chile	45	50	52	53	13.8	13.8	18.7	20.3	62	68	97	102
Colombia	554	731	...	833	9.0	10.3	...	11.3	496	753	800	943
Ecuador	...	109	110	120	...	7.3	8.7	7.9	...	80	95	129
Paraguay	59	97	84	84	10.3	12.0	13.2	12.0	61	116	110	100
Peru	[13] 280	257	226	230	[13] 16.1	16.3	14.1	...	[13] 452	418	319	300
Surinam	3	[4] 1	1	1	6.4	[4] 13.4	16.6	18.2	2	[4] 1	1	1
Uruguay	[14] 222	233	263	276	6.3	6.7	8.1	6.7	139	156	212	184
Venezuela	[15] 263	310	277	259	[15] 13.8	11.4	12.1	12.6	[15] 361	355	335	326
Total	***10 000***	***8 400***	***9 900***	***8 500***	***15.3***	***12.6***	***13.6***	***12.7***	***15 300***	***10 540***	***13 300***	***10 900***

TABLE 1. — AREA, YIELD, AND PRODUCTION OF MAIZE IN SPECIFIED COUNTRIES *(continued)*

Continent and country	Area				Yield				Production			
	1934-38	1948-52	1953	1954	1934-38	1948-52	1953	1954	1934-38	1948-52	1953	1954
ASIA	..... 1 000 hectares				..... 100 kg/hectare				..... 1 000 metric tons			
Afghanistan	...	...	...	350	...	...	...	...	...	...	...	...
British N. Borneo	1	2	2	2	[16] 8.4	12.4	...	...	[16] 1	2	1	1
Burma	84	[17] 63	70	63	4.7	[17] 4.4	4.8	4.8	39	[17] 28	34	30
Cambodia	...	[18] 28	...	...	...	...	...	...	...	[9] *45	...	...
Ceylon	...	14	18	...	...	5.2	5.8	...	...	7	10	...
China												
22 provinces	[19] 4 712	*4 945	...	...	[19] 13.8	*13.5	...	...	[19] 6 497	*6 695	...	...
Manchuria	1 329	[9] *3 175	...	...	15.1	[9] *13.0	...	...	2 007	[9] *4 120	...	...
Taiwan (Formosa)	[6] 2	5	6	...	[6] 10.7	14.1	14.4	...	[6] 2	7	8	...
India	2 970	3 349	3 788	3 774	[8] 7.4	6.5	8.0	7.9	[8] 2 210	2 165	3 011	2 991
Indonesia												
Java and Madura	2 048	[9] 1 625	1 500	1 998	9.7	[9] 6.8	8.7	10.4	1 978	[9] 1 099	1 303	2 084
Other islands	...	[9] 395	470	502	...	[9] 11.1	10.9	11.6	...	[9] 437	512	584
Iran	...	[9] 6	...	...	...	...	...	...	...	[9] 6	...	...
Iraq	...	20	8	5	...	6.8	...	...	...	14	8	4
Israel [20]	[21] 7	[4] 8	5	11	[21] 10.9	[4] 10.1	...	...	[21] 8	[4] 8	11	23
Japan	[22] 51	40	47	46	[22] 14.6	14.2	14.0	12.2	[22] 75	57	66	56
Korea	[23] 117	...	...	...	[23] 7.8	...	...	...	[23] 91	...	...	...
Korea, South	[23] (12)	21	19	21	[23] (6.6)	...	6.2	5.9	[23] (8)	12	12	13
Laos	...	[4] 17	12	...	...	[4] 6.6	6.8	...	...	[4] 11	..	..
Lebanon	...	7	8	7	...	18.9	...	18.8	...	12	...	13
Malaya, Fed. of	...	3	2	4	...	[1] 12.6	...	...	...	[1] 6	...	...
Pakistan	[8] 329	393	432	432	[8] 11.1	9.8	10.3	10.3	[8] 364	584	444	447
Philippines	695	969	1 120	1 394	6.1	7.2	7.0	5.5	427	696	781	770
Portuguese Timor	...	...	...	...	...	...	...	...	...	[18] 25	28	...
Saudi Arabia	...	[1] 15	...	...	...	[1] 13.8	...	...	...	[1] 20	...	...
Syria	18	24	18	17	12.5	13.2	12.3	13.7	22	31	22	24
Thailand	8	34	47	52	6.1	9.1	10.8	11.9	5	31	51	62
Turkey	448	599	621	720	13.1	12.5	12.2	...	587	747	759	914
Viet-Nam	[24] 183	...	...	...	[24] 10.7	...	...	...	[24] 195	...	...	...
Total	***13 500***	***16 500***	***16 800***	***17 800***	***11.3***	***10.5***	***10.9***	***10.9***	***15 300***	***17 200***	***18 400***	***19 400***

TABLE 1. — AREA, YIELD, AND PRODUCTION OF MAIZE IN SPECIFIED COUNTRIES *(continued)*

Continent and country	Area				Yield				Production			
	1934-38	1948-52	1953	1954	1934-38	1948-52	1953	1954	1934-38	1948-52	1953	1954
AFRICA	1 000 hectares				100 kg/hectare				1 000 metric tons			
Algeria	7	7	9	8	6.9	9.1	13.9	11.6	4	6	12	...
Anglo-Egypt. Sudan	11	17	23	...	10.7	[4] 8.0	9.5	...	12	[4] 14	22	...
Angola	531	...	...	...	6.0	...	...	...	321	[25] *135	...	...
Basutoland	130	...	...	...	5.4	...	...	...	70	...	...	...
Bechuanaland	[26] 15	6	12	16	...	...	1.1	...	—	1	1	3
Belgian Congo	[27] 74	337	349	347	...	9.6	9.4	9.3	...	324	327	322
British Cameroons	[28] 8	...	...	...	[28] 12.5	...	...	...	[28] 10	...	...	...
Cape Verde Islands	[29] 22	...	...	...	[29] 3.2	...	...	...	[29] 7	...	...	...
Egypt	649	660	847	800	24.9	20.9	21.9	21.9	1 616	1 378	1 853	1 752
Ethiopia & Eritrea, Fed. of												
Eritrea	[20] 7	23	20	...	[16] 6.1	4.5	...	...	[16] 4	10	20	...
Ethiopia [30]	...	...	...	...	...	...	...	...	...	150	150	150
French Cameroons	54	129	108	107	6.0	7.8	8.6	9.7	33	101	93	94
French Equat. Africa	[4] 33	16	35	...	...	...	...	...	[31] 38	[9] 10	25	...
French Morocco	431	512	508	*497	4.9	5.8	5.8	*5.5	213	296	296	*256
French Togoland	[16] 75	133	125	126	[16] 6.8	3.5	4.2	...	[16] 51	47	52	...
French West Africa	[9] 656	577	693	...	[9] 8.1	5.9	5.1	...	[9] 532	342	354	...
Gambia	...	[17] 1	...	...	...	[17] 12.6	...	...	...	[17] 2	...	...
Gold Coast and British Togoland	...	[9] 143	143	143	...	[9] 11.7	11.8	...	...	[9] 168	169	...
Kenya	201	[1] 331	...	...	10.5	...	...	...	212	[2] 488	...	...
Farms and estates	...	55	67	*70	...	16.9	15.0	*18.6	...	95	100	130
Liberia	...	...	...	...	...	...	...	...	...	[25] 20	...	...
Libya	—	1	...	...	...	...	...	...	—	1	...	...
Madagascar	102	84	83	69	9.9	8.3	8.7	8.1	102	70	73	56
Mauritius	1	3	2	...	23.1	15.9	...	...	1	5	3	...
Mozambique	[9,32] 27	...	...	...	[9,32] 8.8	[17] 9.3	...	...	[9,32] 24	...	...	...
Nigeria	...	[17] 808	...	...	...	...	...	...	...	[17] 755	...	...
Reunion	[15] 8	[4] 8	6	...	...	[4] 9.3	...	...	...	7	5	5
Rhodesia and Nyasaland, Fed. of												
Southern Rhodesia												
Farms and estates	109	139	146	162	13.2	12.8	17.1	15.2	144	167	249	246
Villages	...	[1] 279	...	...	...	[1] 4.6	...	...	[4] 89	171	227	...
Northern Rhodesia												
Farms and estates	17	39	47	...	13.0	15.7	14.6	...	22	62	69	...
Villages [33]	...	...	...	...	...	...	...	...	...	[9] 23	...	...
Nyasaland [34]	...	...	...	...	...	...	...	...	...	30	49	52

TABLE 1. — AREA, YIELD, AND PRODUCTION OF MAIZE IN SPECIFIED COUNTRIES (*concluded*)

Continent and country	Area				Yield				Production			
	1934-38	1948-52	1953	1954	1934-38	1948-52	1953	1954	1934-38	1948-52	1953	1954
	..... 1 000 hectares				..... 100 kg/hectare				..... 1 000 metric tons			
AFRICA (*concluded*)												
Ruanda-Urundi	49	117	133	133	4.4	9.2	9.7	11.0	21	108	129	146
Sierra Leone	...	[9] 8	...	...	...	...	...	...	...	[1] 8	...	...
Somalia	[35] 14	18	25	34	[35] 10.1	8.4	...	...	[35] 14	15	20	35
South West Africa	3	[4] 12	...	...	15.1	[4] 9.6	...	...	5	[4] 12	...	...
Spanish Morocco	[9] 4	6	6	7	[9] 6.7	...	...	10.0	[9] 3	6	6	7
Swaziland	18	[2] 160	...	...	3.2	...	...	...	6	...	45	...
Tanganyika	[5] 422	[4] 233	...	...	...	[1] 7.5	...	...	...	[1] 175	...	...
Tunisia [36]	21	13	11	19	2.6	...	...	...	6	4	2	2
Uganda	35	121	268	...	...	[9] 8.9	...	...	...	[9] 141	...	...
Union of S. Africa [37]	2 357	2 811	[14] 3 557	[14] 3 440	...	8.9	...	...	1 995	2 453	3 554	3 318
Zanzibar and Pemba	—	[17] 1	...	...	—	...	...	...	—	—	...	...
Total	***6 700***	***8 700***	***10 300***	***10 100***	***9.3***	***9.4***	***10.0***	***9.8***	***6 200***	***8 200***	***10 200***	***9 900***
OCEANIA												
Australia	126	72	72	69	14.8	17.6	17.9	19.0	186	127	129	131
Hawaii	[38] 1	—	—	—	[38] 9.8	11.3	...	—	[38] 1	—	—	—
New Caledonia	1	1	1	...	24.6	11.5	...	...	1	—	1	—
New Zealand	3	3	*2	...	28.6	37.1	...	...	8	10	*9	...
Total	130	75	75	75	15.0	18.0	18.0	19.3	200	140	140	140
WORLD TOTAL (excl. U.S.S.R.)	***83 900***	***84 000***	***87 900***	***86 900***	***13.1***	***16.4***	***16.6***	***15.8***	***110 300***	***137 300***	***145 500***	***137 300***
REGIONAL TOTALS												
Europe	11 700	11 000	11 500	11 700	14.8	13.2	14.4	12.5	17 400	14 600	16 600	14 600
North America	37 900	33 600	32 800	32 700	14.0	24.4	24.9	23.6	53 200	82 100	81 600	77 000
Latin America	14 000	14 100	16 400	14 500	12.8	10.7	11.4	11.2	18 000	15 100	18 600	16 300
Near East	1 300	1 900	2 100	2 300	18.5	13.6	14.7	14.0	2 400	2 600	3 100	3 200
Far East	13 000	15 500	15 800	16 500	11.2	10.4	11.0	11.0	14 600	16 200	17 400	18 200
Africa	5 900	7 800	9 200	9 100	7.6	8.5	8.9	8.8	4 500	6 600	8 100	7 900
Oceania	130	75	75	75	15.0	18.0	18.0	19.3	200	140	140	140

[1] 1948 and 1949. — [2] 1948. — [3] 1936-39. — [4] Average of 4 years. — [5] 1938. — [6] 1931-35. — [7] Area refers to principal crop; production includes mixture. — [8] 1936-38. — [9] Average of 3 years. — [10] 1930. — [11] 1929. — [12] Includes estimates of grain equivalent of maize used for silage or fodder and maize hogged off or grazed. — [13] 1928 — [14] Area planted. — [15] 1936. — [16] 1934-37. — [17] 1950. — [18] Average of 2 years. — [19] 1934-37. — [20] Maize and durra. — [21] Palestine, 1935-38 — [22] Includes dry equivalent of maize harvested green. — [23] 1930, 1934 and 1936. — [24] Area relating to Tonkin, Annam and Cochin China, — [25] 1951. — [26] 1916. — [27] 1935-38. — [28] 1927. — [29] 1934 and 1938. — [30] Standing estimate. — [31] 1934 and 1935. — [32] On farms and estates. — [33] Production for market in maize control areas. — [34] Commercialized village production. — [35] 1934-36. — [36] Includes sorghum. — [37] Area on farms and estates only. — [38] 1939.

SOURCE: *FAO Yearbook of Food and Agricultural Statistics*, Volume 9, Part I, 1955.

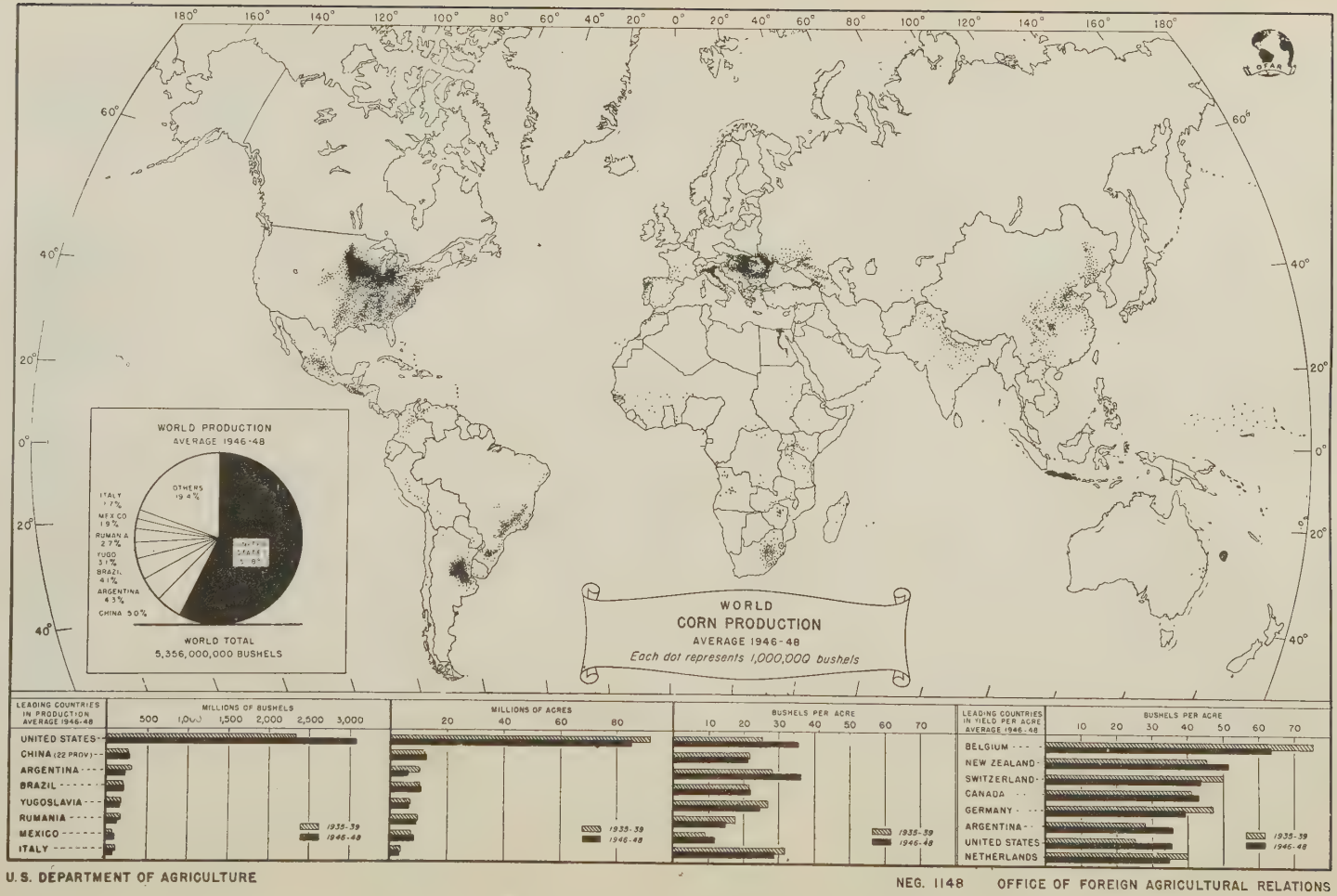


FIGURE 3. - *World production of maize, average of 1946-1948.*

(Courtesy, United States Department of Agriculture)

Maize is the most important crop of American agriculture. It furnished the food and entered into part of the religious life of the Indians. It aided in the settlement and development of the New World, and now is the backbone of American agriculture. As shown in Table 2, maize in the United States usually exceeds the combined totals of wheat, oats, soybeans for beans, barley, and rye in production and value.

TABLE 2. — MAIZE IN THE UNITED STATES USUALLY EXCEEDS TOTALS OF WHEAT, OATS, SOYBEANS FOR BEANS, BARLEY AND RYE IN PRODUCTION AND VALUE

Crop	Acres harvested, in 1 000 acres	Production		Value of production, in 1 000 U.S. dollars
		Bushels, per acre	Total, in 1 000 bushels	
		1953		
Maize	*80 279*	*39.6*	*3 176 615*	*4 605 423*
Wheat, all	67 608	17.3	1 168 536	2 348 852
Oats	39 358	30.9	1 216 416	892 598
Soybeans for beans	14 366	18.3	262 341	667 556
Barley	8 534	28.2	241 015	271 132
Rye	1 382	13.0	17 998	21 498
Total, 5 crops except maize	*131 248*	...	*2 906 306*	*4 201 636*
		Ten-year average, 1942-1951		
Maize	*86 447*	*35.2*	*3 036 380*	...
Wheat, all	63 910	17.1	1 088 548	...
Oats	39 503	33.5	1 324 614	...
Soybeans for beans	11 114	19.7	219 596	...
Barley	11 831	25.1	295 299	...
Rye	2 108	12.2	25 837	...
Total, 5 crops except maize	*128 466*	...	*2 953 894*	...

SOURCE: Agricultural Marketing Service, U.S. Department of Agriculture.

The acreage, yield per acre, and production of maize in the United States are shown in Table 3. The 10 leading States in acreage of maize harvested during the 10-year period, 1945-1954, were Iowa, Illinois, Nebraska, Minnesota, Indiana, Missouri, South Dakota, Ohio, Georgia, and Alabama. Leading States in yields per acre during the same 10-year period were: Washington, Illinois, Ohio, Idaho, Indiana, Iowa, Wisconsin, New Jersey, Massachusetts, and Connecticut. States leading in total production were Iowa, Illinois, Minnesota, Indiana, Nebraska, Ohio, Missouri, Wisconsin, South Dakota, and Kentucky.

TABLE 3. — ACREAGE, YIELD PER ACRE AND PRODUCTION OF MAIZE IN THE UNITED STATES [1]

State	Acreage			Yield per acre			Production		
	Harvested		For harvest 1956	Average 1945-54	1955	Indicated 1956	Average 1945-54	1955	Indicated 1956
	Average 1945-54	1955							
	..... 1 000 acres			..... Bushels			..... 1 000 bushels		
Maine	13	12	11	36.0	36.0	37.0	463	432	407
New Hampshire	12	11	10	43.8	48.0	44.0	540	528	440
Vermont	60	62	61	45.7	52.0	49.0	2 738	3 224	2 989
Massachusetts	35	30	29	48.4	50.0	51.0	1 665	1 500	1 479
Rhode Island	7	6	6	41.7	46.0	42.0	304	276	252
Connecticut	41	39	43	46.6	42.0	49.0	1 912	1 638	2 107
New York	657	718	696	42.0	47.5	45.0	27 688	34 105	31 320
New Jersey	187	202	196	48.7	27.0	55.0	9 114	5 454	10 780
Pennsylvania	1 335	1 334	1 321	46.0	46.0	47.0	61 501	61 364	62 087
Ohio	3 550	3 745	3 670	52.2	59.0	53.0	185 752	220 955	194 510
Indiana	4 578	4 931	4 783	51.2	56.0	52.0	234 929	276 136	248 716
Illinois	8 873	9 357	8 889	52.6	56.0	58.0	467 584	523 992	515 562
Michigan	1 706	2 004	1 984	40.0	46.5	43.0	68 524	93 186	85 312
Wisconsin	2 565	2 740	2 767	49.5	50.0	57.0	126 847	137 000	157 719
Minnesota	5 451	5 815	5 641	43.8	49.0	51.0	238 754	284 935	287 691
Iowa	10 734	10 767	10 659	50.2	48.5	51.0	539.996	522 200	543 609
Missouri	4 100	4 236	4 151	34.5	39.0	41.0	141 798	165 204	170 191
North Dakota	1 194	1 396	1 326	20.7	22.5	23.0	24 662	31 410	30 498
South Dakota	3 910	4 158	3 784	27.4	21.0	25.0	106 860	87 318	94 600
Nebraska	7 325	5 968	6 207	30.2	18.0	32.0	220 863	107 424	198 624
Kansas	2 529	1 624	1 592	24.4	21.0	24.0	61 628	34 104	38 208
Delaware	150	170	153	40.2	36.0	50.0	6 091	6 120	7 650
Maryland	473	519	477	44.2	40.5	47.0	20 922	21 020	22 419
Virginia	1 008	865	796	37.2	38.0	37.0	37 575	32 870	29 452
West Virginia	248	187	170	40.0	39.0	40.0	9 889	7 293	6 800
North Carolina	2 188	2 073	1 969	28.6	34.0	32.0	62 535	70 482	63 008
South Carolina	1 340	1 048	985	18.2	28.0	21.0	24 567	29 344	20 685
Georgia	3 091	2 795	2 711	15.2	24.0	23.0	46 942	67 080	62 353
Florida	611	592	580	13.8	20.0	22.0	8 369	11 840	12 760
Kentucky	2 182	1 933	1 856	34.8	41.0	42.0	76 049	79 253	77 952
Tennessee	2 070	1 751	1 769	28.0	35.0	35.0	58 149	61 285	61 915
Alabama	2 538	2 267	2 244	17.4	30.0	27.0	44 008	68 010	60 588
Mississippi	2 019	1 614	1 485	19.3	30.0	30.0	38 998	48 420	44 550
Arkansas	1 127	663	650	19.4	29.5	30.0	22 488	19 558	19 500
Louisiana	809	639	613	18.0	29.0	26.5	14 348	18 531	16 244
Oklahoma	956	338	318	17.8	24.0	21.0	17 824	8 112	6 678
Texas	2 524	2 012	1 891	17.6	24.0	17.0	44 209	48 288	32 147
Montana	170	186	171	15.2	21.5	14.5	2 586	3 999	2 480
Idaho	31	55	59	52.0	62.0	64.0	1 633	3 410	3 776
Wyoming	56	71	67	18.2	24.5	20.0	1 009	1 740	1 340
Colorado	533	497	383	25.5	33.5	36.0	13 328	16 650	13 788
New Mexico	84	52	51	15.5	21.0	20.0	1 272	1 092	1 020
Arizona	32	50	45	13.6	25.0	28.0	436	1 250	1 260
Utah	31	40	40	40.6	46.0	58.0	1 290	1 840	2 320
Nevada	2	3	3	35.3	40.0	42.0	91	120	126
Washington	22	38	40	58.2	74.0	75.0	1 281	2 812	3 000
Oregon	27	42	28	43.2	61.0	62.0	1 157	2 562	1 736
California	78	245	216	39.3	66.0	65.0	3 219	16 170	14 040
United States	*83 260*	*79 900*	*77 596*	*37.1*	*40.6*	*42.1*	*3 084 389*	*3 241 536*	*3 266 688*

[1] This Table covers maize for all purposes, including hogged and siloed maize, and that cut and fed without removing the ears, as well as that husked and snapped for grain. The yield for grain, with an allowance for varying yields of maize for other purposes, is applied to the total acreage to obtain an equivalent production expressed in terms of grain.

SOURCE: Agricultural Marketing Service, U. S. Department of Agriculture.

Factors Affecting Production

Adaptation of varieties, climate, soil fertility, production practices, and economic factors greatly affect the production of maize. Genetic limitations and possibilities of the plant are discussed in Chapters 10 to 15, inclusive. The crop performs best on well-drained, fertile soils in areas with high summer temperatures, warm nights and extensive rainfall during the growing season.

The amount, distribution, and efficiency of rainfall are important factors in maize production. As shown in Figure 4, there is considerable variation in rainfall throughout the world. Based on information from the United States Weather Bureau, average precipitation in the world as a whole is approximately 38 to 40 inches per year. The annual average is about 26 inches over the land and 44 inches over the sea.

Russell and Danielson (1956) state that, in much of the corn belt of the United States, the water required to produce high yields of maize exceeds by 50 percent or more the normal rainfall for the months of June, July, and August. High levels of production, therefore, are largely dependent on the utilization of water stored in the soil profile. They found the crop utilized water to a depth of 5 feet or more in a deep Brunizem soil from mid-June to mid-September. Grain yields in bushels per acre ranged from 45 for treatment 1 (no rainfall by means of water impermeable covers on the soil surface), 92 for treatment 2 (natural rainfall), and 126 for treatment 3 (natural rainfall plus irrigation water applied in four 2-inch applications). Total water disappearance under the three widely different moisture treatments, however, was proportional to yield. About 7 bushels of grain was produced per inch of water disappearance.

Low or poor distribution of rainfall adversely affects yield. Heat and drought during the pollination period often results in dessication of leaf tissue and poor seed setting. Excessive rainfall, however, causes leaching of soil nutrients and may increase incidence of certain diseases. Humidity affects evaporation and thus the efficiency of rainfall. Humidity varies with the temperature, wind, and amount of rainfall.

Temperature, length of growing season, and length of day also greatly influence the production of maize. The crop prefers average July temperatures between 70° F. and 80° F. in the Northern Hemisphere. Obviously the growing seasons are reversed in the Southern Hemisphere. Most of the maize acreage in Europe is grown south of latitude 50° N. with an average growing season of at least 140 days and an average July temperature of at least 68° F. Most of the crop in the United States is grown south of latitude 45° N.

Emphasis on developing hybrids adapted to varying lengths of growing seasons has resulted in expanding production in many areas. For example,

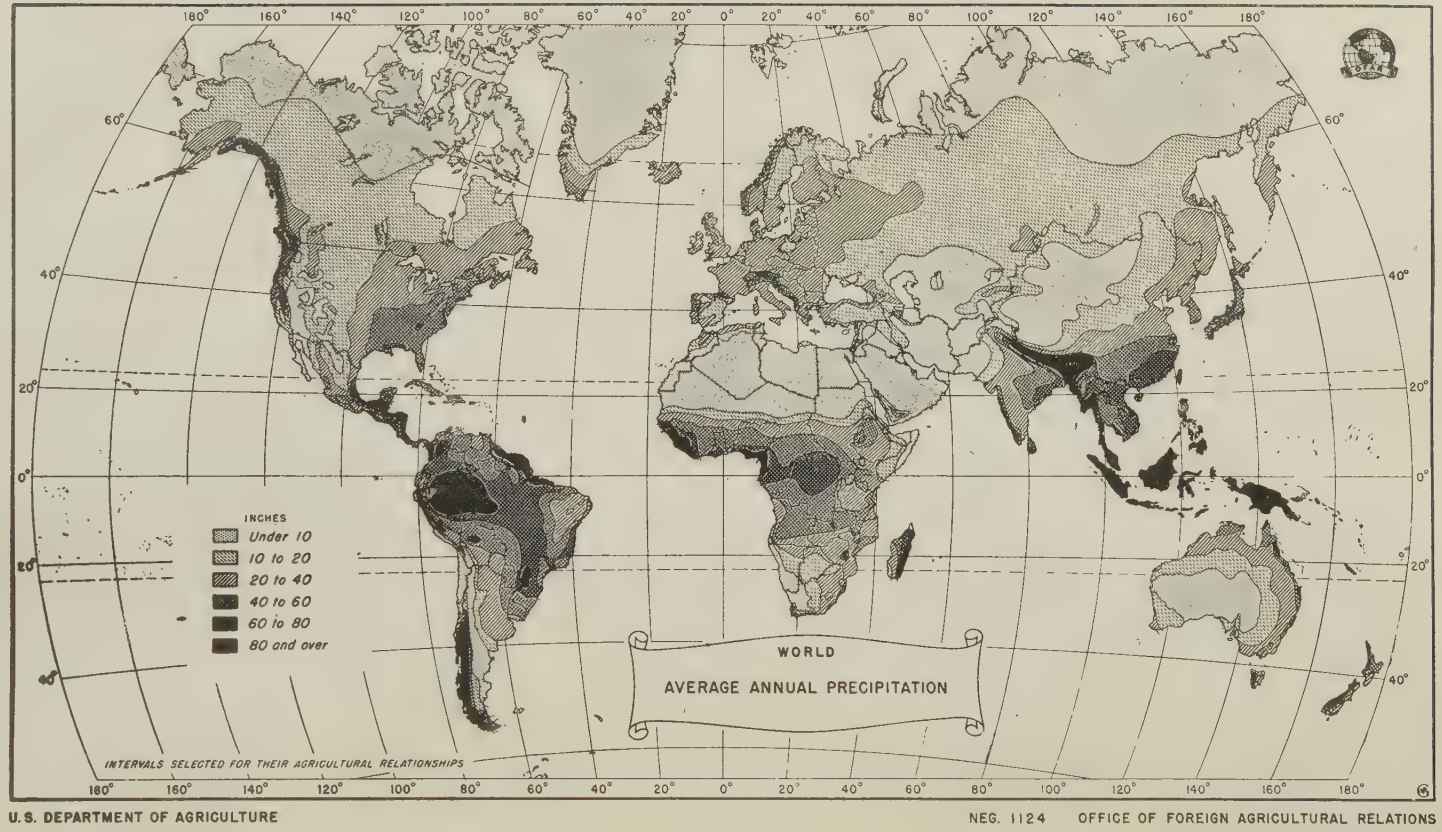


FIGURE 4. - *Average annual precipitation in the world.*

(Courtesy, United States Department of Agriculture)

FIGURE 5. - *Grain yields on the Morrow Plots at the University of Illinois range from 16 bushels per acre on the untreated, continuous maize plot to 100 bushels per acre on the fertilized, maize-oats-clover plot.*

(Courtesy, A. L. Lang)

locations of the FAO co-operative hybrid maize tests in 1952 ranged from Vidarshov, Norway, at a latitude of 60° 48′ N. to Sids, Egypt, at 28° 54′ N. (Jugenheimer and Silow, 1954). The U.S. and Canadian hybrids provided by FAO had relative maturity ratings of 70 to 155 days which were based on ear moisture content at the time of harvest under growing conditions in Minnesota.

Soil fertility is another important factor in maize production. The crop is grown on a wide variety of soils but performs best on well-drained, aerated, deep, warm loams containing an abundance of organic matter, nitrogen, phosphorus and potassium. Records kept on test plots at the University of Illinois for more than seventy-five years show grain yields ranging from about 16 bushels per acre on the untreated continuous-maize plot to more than 100 bushels per acre on the maize-oats-clover plot that has been given suitable amounts of fertilizer (Figure 5). Food for plants is just as necessary as food for humans and animals. Genes for high yield in adapted maize hybrids can reach fullest expression only when the plant is grown on soils well supplied with balanced amounts of plant food.

Cultural practices and economic factors influence the production of maize. An abundance of labor and small size of farms contribute to a laborious, primitive type of agriculture. Extensive use of labor-saving machinery is favored by larger farms of fairly level topography.

Walker (1954) reviewed the extent of the recent trend in the United States toward less labor, more machinery, higher yields, and much greater

crop-labor productivity. Time spent per acre of maize harvested dropped from 35 man-hours in the period 1910-14 to 13 man-hours at the present time. During this period, bushels per acre increased from 26 to 38, and man-hours per 100 bushels decreased from 135 to 34.

Hainsworth, *et al.* (1942) show how size of machinery, method of harvesting, and acre yields affect the quantity of labor used for growing and harvesting an acre of maize (Figure 6). Relatively little labor is needed in the western Corn Belt when tractor power is used and when the crop is harvested with a mechanical two-row picker. The use of animal power and hand-harvesting in the same area almost doubled the labor used. An acre of maize in east Texas required 36 hours of labor compared to only 9 hours in the western Corn Belt. Changes in technology and labor requirements in crop production in the United States were reported (Macy, Arnold and McKibben, 1938).

Role of Hybrid Maize

Hybrid maize was not considered practical until Jones (1919, 1922) suggested the use of the double cross. The development of hybrid maize, however, is the culmination of the efforts of many men working at many public and private research institutions over a period of years. Therefore, the use and value of hybrid maize cannot be accredited to any one man or to any one organization or institution.

There has been a rapid acceptance of hybrid maize in the United States since 1933 (Table 4). The acreage in the Corn Belt increased from 0.2 percent in 1933 to over 96 percent at the present time. Percentage of the maize acreage planted with hybrid seed in the United States increased from 0.1 percent in 1933 to 90.8 percent in 1956. Hybrid acreage in the United States increased from 143,000 acres in 1933 to nearly 72,000,000 acres in 1956.

Yugoslavia, Italy, Egypt, Turkey, Morocco, Portugal, France, Spain and Greece grow large acreages of maize. Nearly 18 million acres (7,234,232 hectares) of maize were grown in the 15 countries listed in Table 5 in 1955. This area produced 13,243,219 tons (nearly 500 million bushels) of grain. This production, however, might be doubled by the use of adapted hybrids and modern production practices (Jugenheimer, 1955a).

Hybrid maize is rapidly replacing open-pollinated varieties in European and Mediterranean countries (Table 5). Early maturing hybrids have made possible the growing of maize in many new areas of Belgium, the Netherlands, and France. Nearly all of this new acreage is planted to hybrids. Today more than 23 percent of Italy's large maize acreage is

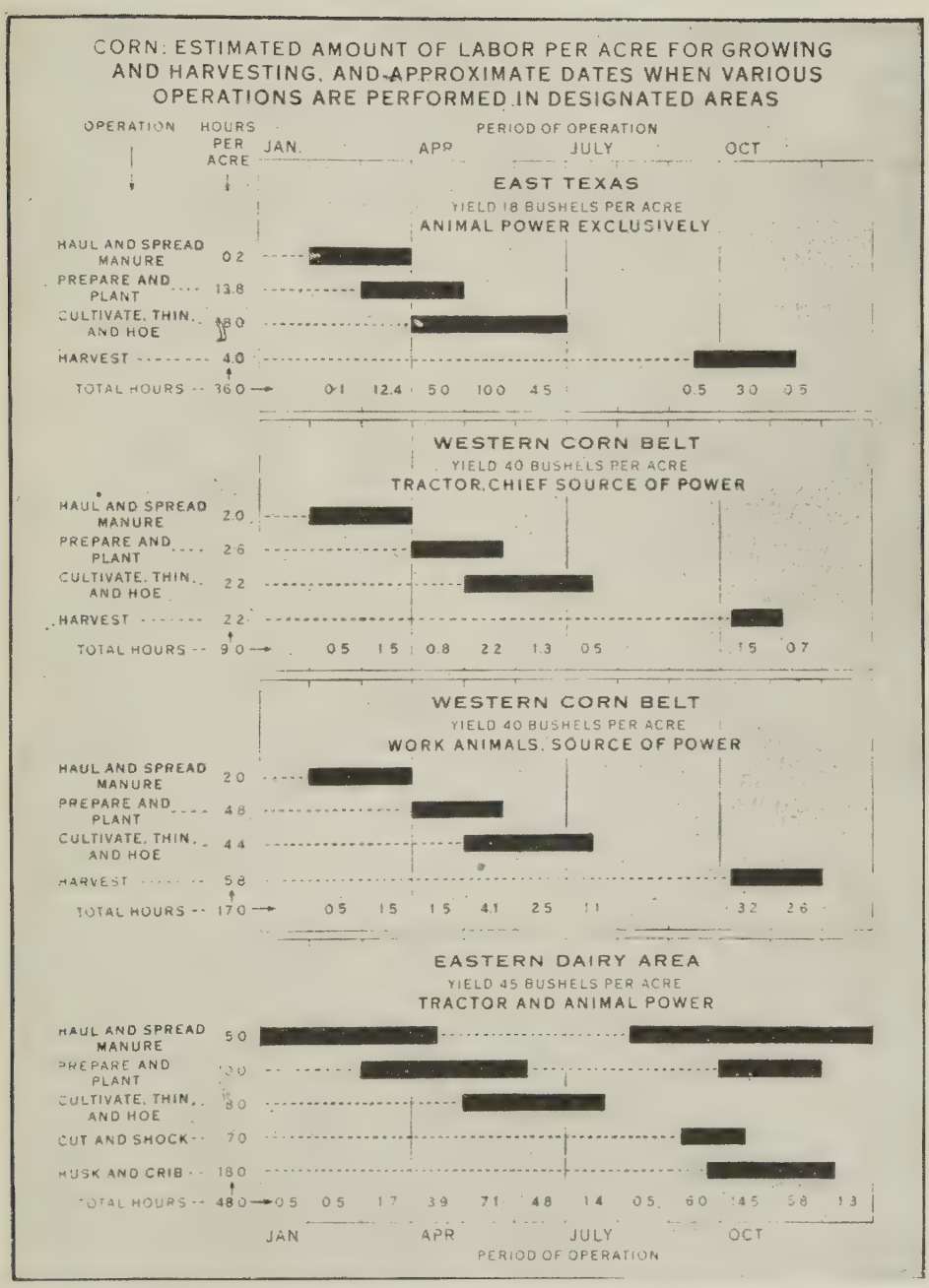


FIGURE 6. - *Size of machinery, method of harvesting and acre yields greatly affect the quantity of labor used for growing and harvesting an acre of maize.*

(Courtesy, R. G. Hainsworth *et al.* 1942)

TABLE 4. — MAIZE ACREAGE PLANTED WITH HYBRID SEED IN THE UNITED STATES, 1933-1956

Year	All maize acreage	Planted with hybrid seed	Indicated hybrid maize acreage
	1 000 acres	Percent	1 000 acres
1933	109 830	0.1	143
1934	100 563	0.4	372
1935	99 974	1.1	1 140
1936	101 959	3.1	3 166
1937	97 174	7.9	7 632
1938	94 473	14.9	14 079
1939	91 639	22.5	20 618
1940	88 692	30.5	27 011
1941	86 837	39.3	34 134
1942	88 818	46.4	41 199
1943	94 341	52.4	49 428
1944	95 475	59.2	56 475
1945	89 261	64.7	57 778
1946	88 898	68.9	61 271
1947	85 038	72.5	61 676
1948	85 522	76.0	64 990
1949	86 738	78.3	67 901
1950	82 859	78.0	64 613
1951	83 275	81.5	67 889
1952	82 230	84.6	69 528
1953	81 574	86.5	70 546
1954	82 185	87.3	71 788
1955	81 492	89.4	72 856
1956	79 016	90.8	71 757

SOURCE: Agricultural Marketing Service, U.S. Department of Agriculture.

TABLE 5. — PROGRESS IN HYBRID MAIZE PRODUCTION IN EUROPE AND THE MEDITERRANEAN REGION, 1953-1955

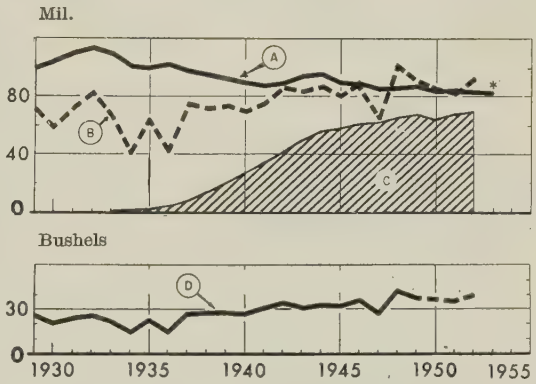
Country	Maize area in hybrids			Estimated increased maize production from the use of hybrids					
	1953	1954	1955	1953	1954	1955	1953	1954	1955
	Percent			Tons			U.S. dollars		
Algeria	32.5	25.0	25.0	2 000	2 000	4 000	142 860	150 000	400 000
Austria	5.0	5.0	10.0	2 400	1 500	5 000	168 000	120 000	400 000
Belgium	99.0	99.0	99.0	2 000	2 000	800	140 000	140 000	50 000
Egypt	0.02	1.0	2.4	9	784	14 000	5 600	390 000	1 000 000
France	28.0	31.0	31.5	115 000	188 000	130 000	11 714 300	18 575 000	13 000 000
Greece	10.0	10.0	10.0	10 000	10 000	10 000	1 000 000	1 000 000	800 000
Israel	16.0	16.0	58.0	9 000	9 000	9 000	1 350 000	1 350 000	900 000
Italy	15.5	18.8	23.4	300 000	336 000	550 000	21 600 000	26 880 000	41 250 000
Morocco	0.8	0.4	0.4	2 786	3 276	2 500	200 000	260 000	250 000
Netherlands	80.0	86.0	92.0	4 000	3 000	3 000	290 000	237 000	225 000
Portugal	0.9	1.1	0.6	10 245	11 960	6 100	777 206	907 310	500 000
Spain	12.3	15.4	17.3	30 000	55 000	60 000	2 250 000	3 850 000	4 800 000
Switzerland	9.0	15.0	15.0	130	300	300	12 260	28 000	25 000
Turkey	0.0	0.4	0.8	0	1 095	2 200	0	100 500	130 000
Yugoslavia	1.0	2.0	5.0	2 400	14 500	48 000	112 000	1 450 000	4 000 000
Total	*5.9*	*7.4*	*9.0*	*489 970*	*638 415*	*844 900*	*39 762 226*	*55 437 810*	*67 730 000*

SOURCE: Compiled from reports of FAO hybrid maize meetings.

hybrid. In France and Belgium, hybrid maize is replacing some of the beet and potato acreage. In Switzerland, maize can supplement grass for feeding, and aid in eliminating black foot disease of wheat. Adapted hybrids are also rapidly replacing low-yielding varieties in Algeria, Austria, Greece, Israel, Spain, and Yugoslavia.

In Portugal, Egypt, Yugoslavia, Turkey, Austria, Israel, Germany, Morocco, Mexico, Brazil, Peru, Columbia, and many African and Asiatic countries, maize hybrids probably will also rapidly replace low-yielding, open-pollinated varieties.

Conservative estimates indicate that hybrid seed has increased maize production in the United States about 25 percent to 50 percent. Although



A. *Acres*
B. *Production, in tons*
C. *Planted with hybrid seed*
D. *Yield, per planted acre*
* *Prospective planting as of March 1*

FIGURE. 7 - *Maize acreage and production trends in the United States. Expanding use of hybrid maize and modern production practices in the United States have resulted in greatly increasing production on a declining acreage.*

(Courtesy, United States Department of Agriculture)

maize acreage in the United States has been declining during the past 20 years, and now is about one fourth less than during the thirties, production continues upward due to greater use of hybrid seed, mechanization, and fertilizers (Figure 7). Acre yields for the 10-year period, 1941-1950, were 10 bushels per acre over that of 1924-1933, the 10-year period prior to the advent of hybrids.

The United States annually receives increased yields of at least 750 million bushels through the use of hybrids. This is an annual dividend of about $75 on each dollar originally spent on the hybrid maize program. McCall (1944) estimated an increased yield in the United States in 1943 of 669,480,000 bushels. He stated that this increase was sufficient to produce 7,330 million pounds of pork which would be enough to provide 54 pounds of pork for everyone in the nation. Stadler put the value of hybrid maize in the United States during the four-year period, 1942-1945, at more than $2,000 million. He stated that this dividend on hybrid

maize research investment during the war years was equivalent to the cost of developing the atomic bomb.

Almost unknown to the average farmer in 1935, hybrid seed is now planted on 100 percent of the Illinois and Iowa maize acreage. Maize yields in Illinois from 1946 through 1955, when hybrids were grown on most of the acreage, averaged 20 bushels an acre or 59.4 percent more than during the 70-year period (1866-1935) when open-pollinated varieties were grown almost exclusively. Figure 8 shows how the increase in average maize yields in Illinois has been coupled with the increased use of

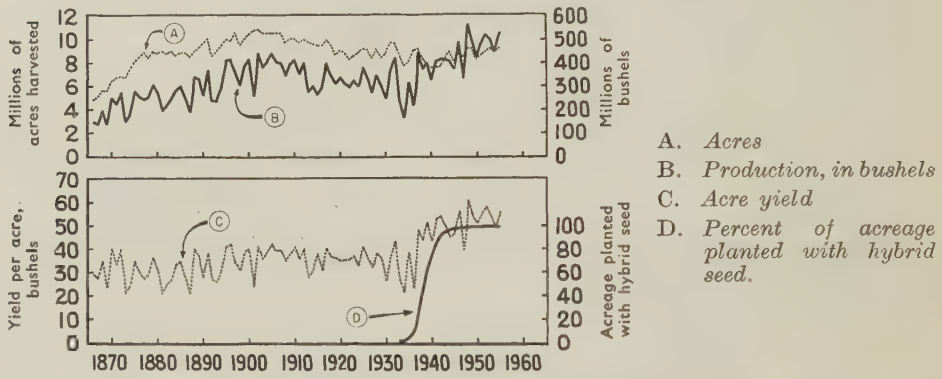


FIGURE 8. - *Illinois maize yields from 1946 through 1955, when hybrids were grown on most of the acreage, averaged 20 bushels an acre or 59.4 percent more than during the 70-year period (1866-1935) when open-pollinated varieties were grown almost exclusively.*

hybrid seed. The better hybrids were also adapted to machine harvesting and more resistant to lodging, diseases, insects, heat and drought.

Earlier maturity, higher yields, better standability, and greater resistance to insects, diseases, and drought are the characteristics of certain American hybrids that have helped boost the acreage and production of maize in Europe and the Mediterranean area. Use of hybrids almost doubled from 1952 to 1953. About 9 percent of the 7,234,232 hectares (nearly 18 million acres) in maize in 17 countries was planted with hybrid seed in 1955. In that year, the increased production from the use of hybrids was 844,900 tons. Potential increases from the use of hybrids in these countries is at least 10 million tons.

The hybrid testing program sponsored by FAO was started with an original investment of only $40,000. The value of the estimated increased production in 15 countries was worth over 24 million dollars in 1952, nearly 40 million dollars in 1953, over 55 million in 1954, and nearly 68 million dollars in 1955 (Table 5). Italy and France received especially large dividends from their hybrid programs. The value of the potential increase from the use of hybrids in the 15-country area is at least $500 million per year.

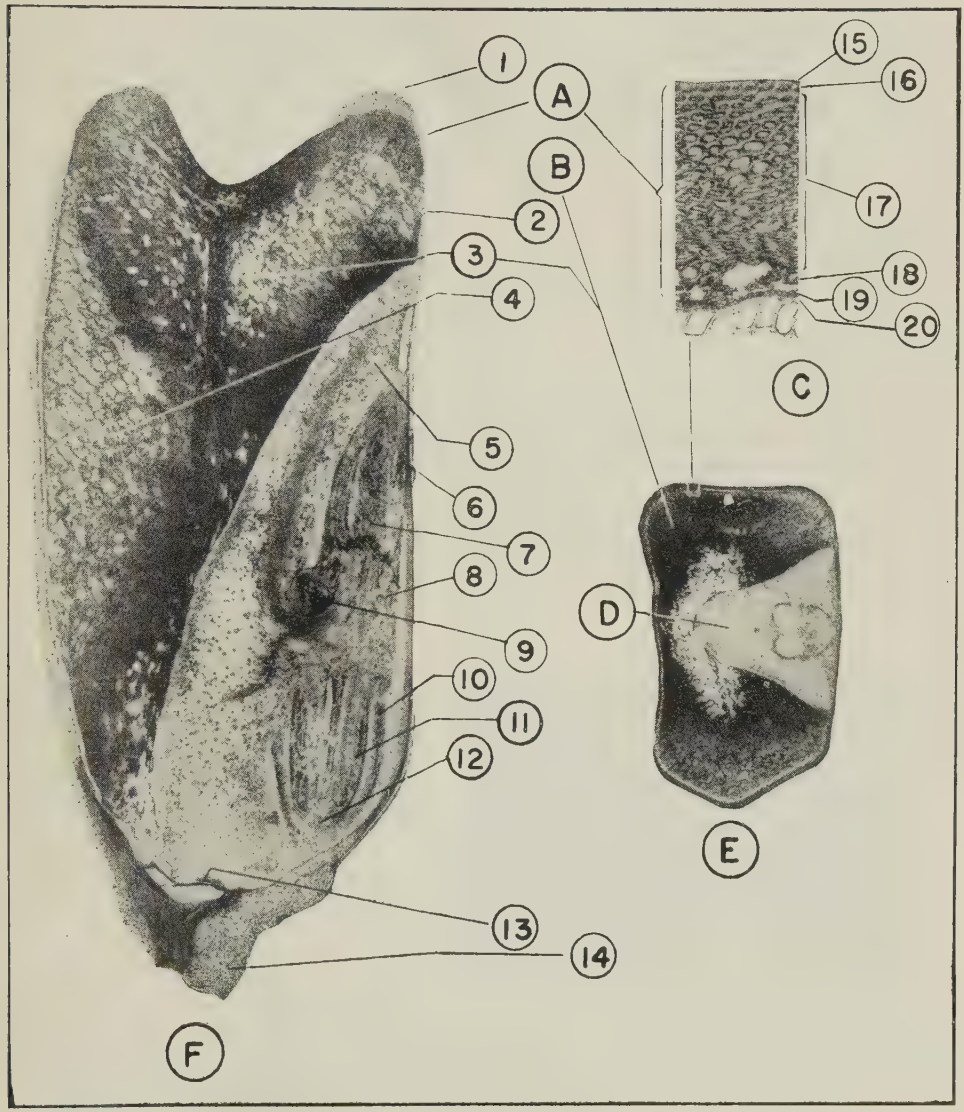


FIGURE 9. - *The structure of the mature maize kernel.*

A. *Pericarp* B. *Endosperm* C. *Cross-section of pericarp, magnified 550 ×* D. *Germ* E. *Cross-section of kernel, magnified 15 ×* F. *Longisection of kernel, magnified 40 ×.*

1. *Silk attachment* 2. *Aleurone layer* 3. *Floury endosperm* 4. *Horny endosperm* 5. *Scutellum* 6. *Coleoptile* 7. *Plumule* 8. *Mesocotyl* 9. *Root bud* 10. *Coleorhiza* 11. *Primary root* 12. *Root cap* 13. *Hilar layer* 14. *Tip cap* 15. *Cuticle* 16. *Epidermis* 17. *Mesocarp* 18. *Cross cells* 19. *Tube cells* 20. *Seed coat*

(Courtesy, United States Department of Agriculture)

Jugenheimer and Silow (1954) reported that the best of 45 American hybrids provided by FAO produced, on an average, 60 percent more grain than the best local, open-pollinated variety in 141 tests in 13 countries in 1952. If the 30 million acres of maize land in Europe were planted to the best available hybrids, the resulting increase in yield would be equivalent to the production of an additional 18 million acres.

Utilization of Maize

Maize is used primarily as a food for humans in most areas of the world, in contrast to the United States where about 90 percent of the crop is fed to livestock.

The structure of the mature maize kernel is shown in Figure 9. The water-free portion of the kernel includes about 77 percent starch, 2 percent sugar, 9 percent protein, 5 percent oil, 5 percent pentosan, and 2 percent ash. The ash of the kernel contains salts of calcium, magnesium, phosphorus, aluminum, iron, sodium, potassium, and chlorine.

Directly, or indirectly, maize provides the United States with more food than any other cereal crop. It provides more animal feed in both

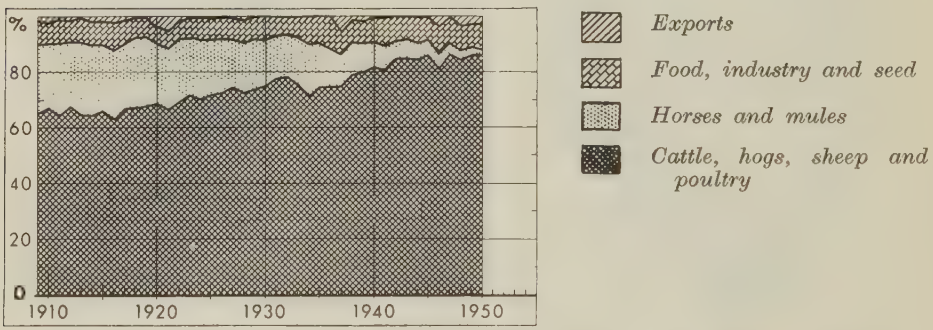


FIGURE 10. - *Trends in the utilization of maize in the United States. Percentages devoted to major types of use, 1910-50: 1926-50, year beginning October; 1909-25, year beginning November.*

(Courtesy, United States Department of Agriculture)

grain and forage than any other grain. Maize also yields more industrial products than any other grain. The industrial users of maize in the United States may be divided into these four categories:

1. mixed feed manufacturers;
2. dry process millers;
3. wet processors;
4. distilling and fermentation industries.

TABLE 6. — UTILIZATION OF MAIZE IN THE UNITED STATES, 1955

State	For grain			For silage			Hogging down, grazing & forage acres
	Acreage harvested	Yield per acre	Production	Acreage harvested	Yield per acre	Production	
	1 000 acres	*Bushels*	*1 000 bushels*	*1 000 acres*	*Tons*	*1 000 tons*	*1 000 acres*
Maine	1	36.0	36	12	11.0	132	...
New Hampshire	2	47.0	94	12	10.5	126	...
Vermont	2	44.0	88	64	10.5	672	2
Massachusetts	5	44.0	220	30	10.5	315	1
Rhode Island	1	43.0	43	5	9.5	48	...
Connecticut	4	40.0	160	34	11.0	374	1
New York	215	46.0	9 890	463	9.8	4 537	19
New Jersey	138	28.0	3 864	59	7.0	413	5
Pennsylvania	1 082	44.0	47 608	285	8.5	2 422	21
Ohio	3 625	60.0	217 500	117	9.8	1 147	38
Indiana	4 808	56.0	269 248	74	10.5	777	49
Illinois	9 067	56.0	507 752	206	10.5	2 163	84
Michigan	1 644	46.0	75 624	253	8.9	2 252	65
Wisconsin	1 667	52.0	86 684	1 095	9.5	10 402	31
Minnesota	5 059	50.0	252 950	698	8.8	6 142	58
Iowa	10 358	46.0	476 468	269	9.5	2 556	140
Missouri	3 939	39.0	153 621	169	7.5	1 268	128
North Dakota	510	25.5	13 005	537	4.1	2 202	349
South Dakota	3 005	23.0	69 115	494	4.5	2 223	618
Nebraska	4 760	18.0	85 680	714	4.0	2 856	476
Kansas	1 039	22.0	22 858	390	3.4	1 326	195
Delaware	164	30.0	4 920	4	8.0	32	2
Maryland	416	39.0	16 224	45	9.5	428	6
Virginia	744	38.0	28 272	86	10.0	860	35
West Virginia	165	39.0	6 435	19	9.5	180	3
North Carolina	1 962	32.5	63 765	52	11.0	572	80
South Carolina	992	28.0	27 776	13	8.5	110	55
Georgia	2 281	22.5	51 322	17	7.0	119	497
Florida	395	19.0	7 505	6	6.0	36	191
Kentucky	1 936	41.0	79 376	45	9.0	405	12
Tennessee	1 640	34.0	55 760	35	9.0	315	57
Alabama	1 985	30.0	59 550	4	7.0	28	161
Mississippi	1 507	30.0	45 210	16	8.5	136	31
Arkansas	606	30.0	18 180	12	7.0	84	16
Louisiana	598	30.0	17 940	6	8.0	48	25
Oklahoma	301	24.0	7 224	29	4.5	130	8
Texas	2 071	23.5	48 668	32	6.0	192	54
Montana	10	24.0	240	53	5.0	265	147
Idaho	30	62.5	1 875	28	15.5	434	2
Wyoming	18	24.0	432	32	9.0	288	20
Colorado	248	29.0	7 192	174	9.5	1 653	75
New Mexico	70	16.0	1 120	5	7.0	35	13
Arizona	39	25.0	975	4	9.0	36	7
Utah	6	38.0	228	28	13.0	364	5
Nevada	...	...	...	3	12.0	36	...
Washington	20	66.0	1 320	14	12.5	175	3
Oregon	18	65.0	1 170	18	12.0	216	4
California	193	60.0	11 580	55	13.0	715	5
United States	*69 346*	*41.2*	*2 856 767*	*6 815*	*7.67*	*52 245*	*3 794*

SOURCE: United States Department of Agriculture.

Trends in maize utilization in the United States during the past 40 years are shown in Figure 10. The Bureau of Agricultural Economics of the United States Department of Agriculture (1951) pointed out major changes in agriculture and in food consumption in the United States during the past 40 years. The gradual shift from the use of horses and mules to tractors for farm power since the first world war released about

20 percent of the maize crop for use in producing meat, milk, eggs, and other food products. The downtrend in the numbers of horses and mules was compensated for by increased numbers of cattle, hogs, and poultry. Livestock feeding accounted for 88 percent to 92 percent of the crop. Exports ranged from 1 percent to 5 percent of the total production. Increased utilization of maize during the past ten years reflects a strong demand, and increased production resulting from higher yields per acre.

The Corn Industries Research Foundation (CIRF 1952a, 1952b, 1954) lists more than 500 important products and by-products of maize and their uses. These many uses are divided among three great consuming groups — livestock, industrial, and human.

Maize is used for livestock feeds in a variety of ways. It may be used for grain, silage, hogging down, grazing, and forage. The utilization of maize in the United States for these purposes is shown in Table 6. Most of the crop in the United States is used for grain. In 1946, 12 percent of the production in the United States was white compared with 41 percent in 1917. Practically all of the crop in Illinois and Iowa is used for grain, while almost half of the crop in Wisconsin is used for silage.

A rather high percentage of the crop in northern Europe is used for fodder or green feed. Maize as a forage crop includes fodder, stover.

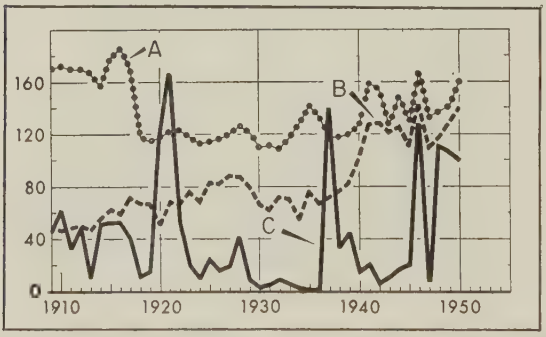


FIGURE 11. - *Nonfeed uses of maize in the United States. Marketing year, 1909-25, year beginning November; 1926-50, year beginning October. Data for 1950 are preliminary.*
(Courtesy, United States Department of Agriculture)

and silage. Fodder consists of the entire fresh or cured plant; stover includes the dried corn stalks minus the ears. In many sections, the entire plant is cut when green and fed, or cured in the shock as fodder. The maize plant when properly cut, chopped and stored is ideal for silage. In some countries, the leaves or tops of the plants are removed and used for feed.

Nonfeed uses of maize in the United States are shown in Figure 11. The production of starch, sugar, sirup, and other wet-produced products

A. *Corn starch*
B. *Corn sugar*
C. *Corn sirup, unmixed*
D. *Dextrines*
F. *Oil*
G. *Feed*

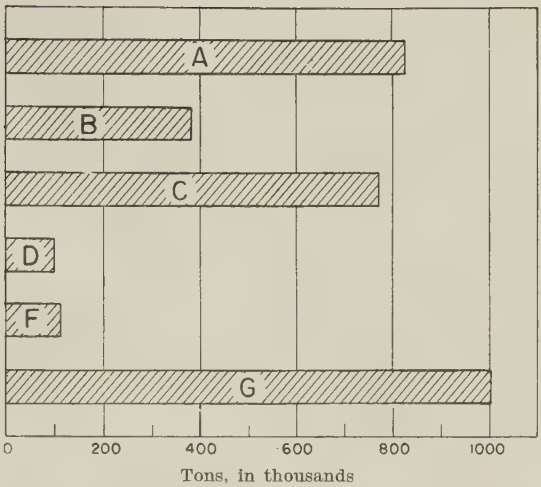


FIGURE 12. - *Products from maize wet milling, 1951, Northern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry, United States Department of Agriculture.*

(Courtesy, R. T. Milner, 1954)

A. *Farm household use*
B. *Breakfast food*
C. *Meat and grits*
D. *Oil*
E. *Feed*

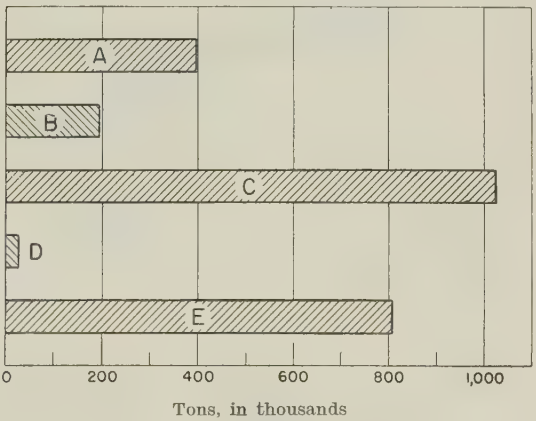


FIGURE 13. - *Products from maize dry milling, 1951, Northern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry, United States Department of Agriculture.*

(Courtesy, R. T. Milner, 1954)

has more than doubled since 1909. Production of alcohol and distilled spirits utilizes 30 million to 50 million bushels of maize. Exports of maize from the United States have varied greatly over the past 40 years. Exports, however, utilize a relatively small proportion of the crop normally grown in the United States.

Use of maize in the United States for food, industry, and seed amounts to about 8 percent to 10 percent of the crop. The mixed feed manufacturing industry is the largest industrial user of shelled grain. By-products of processing are gluten feed, gluten meal, oil cake meal, germ meal, and

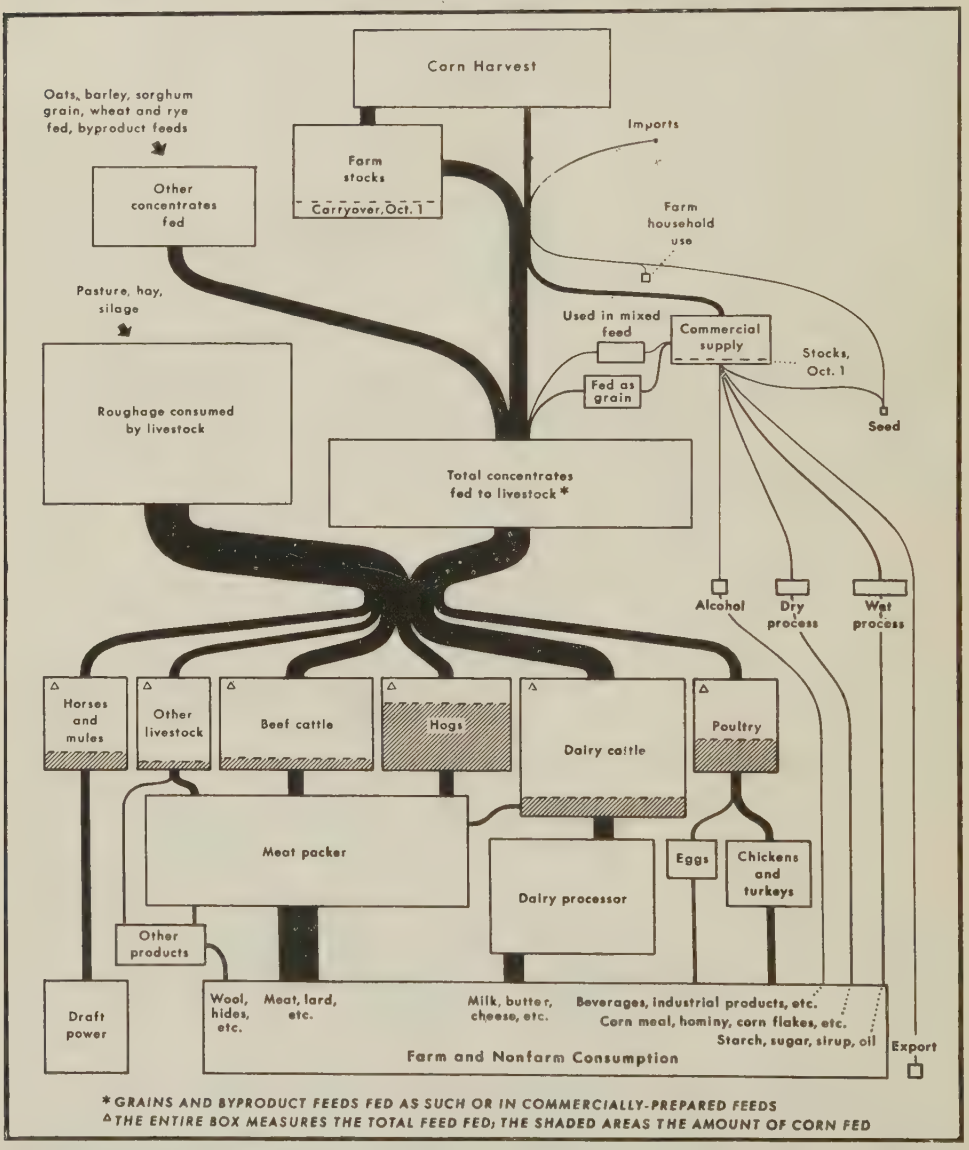


FIGURE 14. - *Movement and utilization of maize in the United States, 1938-1947. Size of the various channels and the shaded areas in the boxes in the lower half of the chart illustrate the importance of maize as a livestock feed in the United States, based on data from 1938-1947.*

(Courtesy, United States Department of Agriculture)

distillers' and brewers' grains. About three fourths of the mixed feed industries' output is manufactured poultry and dairy feeds.

American industries are greatly interested in the starch part of the kernel. Maize is probably the cheapest and the purest organic material of American agriculture available for large-scale industrial use. The wet millers manufacture starch, feed, sirup, sugar, oil and dextrines from maize (Figure 12). They largely use yellow dent, and can use a crop of fairly high moisture content. A bushel of average quality maize containing 16 percent moisture yields about 35 pounds of pearl starch, 1.6 pounds of oil, and the remainder is feed. About 40 pounds of sirup or 27½ pounds of refined sugar may be obtained from a bushel of the crop.

The dry process millers also utilize large quantities of maize. The principal food outlets of the dry miller are corn meal, flour, grits, and breakfast cereals (Figure 13). Grits consist of the coarsely ground endosperm of the kernel from which most of the bran and germ have been separated. Corn flakes are made by rolling grits after they have been flavored.

The distilling and fermentation industries in the United States rank fourth in the industrial use of the maize crop. These industries manufacture ethyl and butyl alcohol, acetone, and whiskey.

Movement and relative uses of maize are summarized in Figure 14. The size of the various channels and the shaded areas in the boxes in the lower half of the chart emphasize the importance of maize for livestock feed.

2. THE MAIZE PLANT

Maize is one of the few economic plants native to America. The recorded history of maize is limited to the years following the discovery of America. Apparently, the first reference to the plant in recorded history occurred on November 5, 1492. On that day two Spaniards, sent out on an exploration expedition by Columbus to the interior of Cuba, returned with a report of " a sort of grain they call maiz which was well tasted, bak'd, and dry'd, and made into flour." Dent, flour, sweet, flint, and popcorn were being grown in America when it was discovered by Columbus.

Botanical Relations

Botanical relatives of maize were discussed by Jenkins (1937), Mangelsdorf (1947a), and Weatherwax (1954). Maize is a grass and belongs to the large and important family, *Gramineae*. It belongs to the tribe, *Maydeae*, which includes eight genera. Five of these are relatively unimportant oriental genera:

1. *Coix* (Job's tears)
2. *Sclerachne*
3. *Polytoca*
4. *Chionachne*
5. *Trilobachne*.

These are native to an area extending from India to Burma through the East Indies and into Australia. *Coix* is the best known genera of the group. The three American genera are:

1. *Zea*, which is of greatest importance;
2. *Tripsacum* (gamagrass), which has some value as a forage crop, but none as a grain crop;
3. *Euchlaena* (teosinte), which appears to be the closest wild relative of maize.

Zea is represented by the single species *Zea mays* which is Indian corn, or maize. Agricultural groups are dent, pop, flour, flint, sweet, and waxy.

Tripsacum, or gamagrass, is found throughout the West Indies, from Mexico to Brazil, and in the eastern and western part of the United States. The diploid form contains 18 pairs of chromosomes and the tetraploid form contains 36 pairs. The plant probably never was used for food by the Indians, but has some value as a forage crop.

Euchlaena, or teosinte, occurs in southern Mexico and in Guatemala. The annual form has 10 pairs of chromosomes like maize, and is the most common type. Perennial teosinte has 20 pairs of chromosomes and is found in a restricted area in Mexico. The annual form is used as a forage plant.

Theories of Origin

The origin of maize is lost in antiquity. The plant is very highly specialized and could not reproduce itself without the aid of man. The ear is especially constructed for producing high grain yields under man's protection. The crop, however, lacks a satisfactory mechanism of seed dispersal and has a low survival value in nature. For example, scores of seedlings emerge when an ear of maize drops to the ground. These seedlings compete among themselves for soil nutrients and moisture and most of them die before they reach the reproductive stage.

Many workers have investigated the origin of maize. Some of these studies have been summarized by Anderson (1947b), Anderson and Brown (1952), Anderson and Cutler (1942), Brown and Anderson (1947), Cutler (1946), Jenkins (1937), Kempton (1931, 1938), Kuleshov (1933), Mangelsdorf (1947a, 1948b, 1950, 1952b), Mangelsdorf and Oliver (1951), Mangelsdorf and Reeves (1938, 1939), Mangelsdorf and Smith (1949a, 1949b), Stoner and Anderson (1949), Vavilov (1931), Weatherwax (1935, 1950, 1954), Weatherwax and Randolph (1955), Wellhausen, *et al.* (1952), and Wissler (1945).

Wild maize has never been found by modern man. Therefore, no one knows when this important plant originated, but the time of origin must have been thousands of years ago. Archaeological and geological excavations and measures of radioactive decay of old ears of maize found in caves indicate that the plant must have originated at least 4,500 years ago. Pollen grains of *Zea*, *Tripsacum*, and *Euchlaena* found under Mexico City are much older (Weatherwax and Randolph, 1955).

Maize may have originated in the highlands of Peru, Bolivia, and Ecuador, because of the great diversity of native forms found in this region. Other investigators believe that maize originated in southern Mexico and Central America, primarily because this appears to be the native home of *Euchlaena*, and also because of the wide diversity of types.

An Asiatic origin of maize has been advanced, but most investigators believe that the plant probably originated in Mexico.

The method of the origin of maize is speculative and controversial, because no wild forms of the crop have been found. A number of theories on the origin of maize have been advanced by investigators, but none of them are entirely satisfactory.

Podcorn often has been mentioned as a wild or primitive type of maize. The kernels are enclosed in a pod which might have been characteristic of the wild plant. Pure podcorn has many of the characteristics expected in the ancestral form of maize. However, the plant differs from ordinary maize in only one gene.

A tripartite hypothesis assumes that:

1. Cultivated maize originated from a wild form of podcorn indigenous to the lowlands of South America.
2. *Euchlaena* is a natural hybrid of *Zea* and *Tripsacum* which occurred after cultivated maize had been introduced by man into Central America.
3. The majority of Central and North American varieties originated from the cross (Mangelsdorf, 1947a).

E. L. Sturtevant (1899) suggested that primitive maize may have been both a podcorn and a popcorn. Mangelsdorf (1950) feels that evidence is accumulating to show that Sturtevant might have been correct. Mangelsdorf's conclusions are based on evidence from cobs and other parts of maize found in a rock shelter in New Mexico, known as the Bat Cave. The oldest cobs, found at the bottom of a heap of refuse, are small but very primitive. The cobs and kernels appear to be a primitive variety with both pod and popcorn characteristics.

Mangelsdorf (1950) suggests that:

"The evolutionary sequence in the Bat Cave indicates that four principal factors operated in the evolution of corn during this period:

1. The pressure of natural selection, one of the most important suppressive factors in evolution, was greatly reduced.
2. Mutations from the more to the less extreme forms of podcorn occurred.
3. Corn was modified by contamination with teosinte.
4. Crossing of varieties and races produced new combinations of characters and a high degree of hybridity."

Weatherwax (1923, 1935, 1954) states that *Zea*, *Tripsacum*, and *Euchlaena* probably arose by divergent evolution from some common ancestor. He points out that the three plants are similar in structural pattern, and believes that visible differences among them might be due

to differential abortion of organs during development. He concludes that the wild ancestor of maize was probably a perennial plant with:

"the habit of teosinte or some of the tropical species of *Tripsacum*, with bushy, branched inflorescences terminating the main stem and the branches.... The small ears, with probably four or eight rows of grains, were probably partly enclosed by enveloping leaf sheaths, and the small grains were wholly or partly covered by the bracts of the spikelet ..... Some of the characteristics of the plant which mitigated against its success in nature, however, made it more useful agriculturally, and domestication made capital of its biological weaknesses."

Randolph (Weatherwax and Randolph, 1955) believes that much of the disagreement concerning the origin of maize has been due to failure to appreciate fully the significance of cytogenetic data on maize and its relatives. Referring to the evolutionary history of maize, he states:

"There is little or no support from cytogenetics or cytotaxonomy for the assumptions that it is

1. a hybrid of teosinte and some unknown member of the *Andropogoneae* (Collins, 1912; Harshberger, 1893);
2. an amphilidiploid hybrid of Asiatic species belonging to the *Maydeae* and *Andropogoneae* (Anderson, 1945);
3. a trigeneric hybrid of podcorn, *Euchlaena*, and *Tripsacum* (Brieger, 1944); or
4. a recent product of the hybridization of a South American derivative of podcorn and Central American *Tripsacum* with teosinte as a by-product (Mangelsdorf and Reeves, 1939).

On the contrary, the cytogenetic evidence offers no serious obstacles to alternative hypotheses that:

1. *Zea*, *Euchlaena*, and *Tripsacum* originated separately from a common ancestral form (Montgomery, 1906; Weatherwax, 1918, 1935); or
2. *Zea* was derived from *Euchlaena* by mutation (Ascherson, 1880; Langham, 1940; Longley, 1941 b)."

Groups of Maize

Maize may be divided into various types differing in character of the seeds. These types are dent, flint, sweet, flour, popcorn, waxy, and podcorn (Figure 15).

Dent is the most widely grown type of maize in the United States. It is characterized by a depression or "dent" in the crown of the seed. The sides of the seed have a corneous starch, while the soft starch extends to the summit of the seed. Rapid drying and shrinkage of the soft starch

FIGURE 15. - *Types of maize differ in character of the seeds.* (Left to right: *dent, flint, pop, flour, sweet, and pod.*)

results in the characteristic denting. The dents of the Corn Belt of the United States probably originated from the mixing of the Northern Flints and the Southern Dents.

Flint maize is rather widely grown in Europe, Asia, Central America and South America. It was grown more widely in the United States in prehistoric and Colonial times than during the present time. In general, the kernels of flint maize are hard and smooth and contain little soft starch. The relative amounts of soft and corneous starch, however, vary in different varieties. Flint maize often is earlier in maturity, germinates better, has earlier plant vigor, and more tillers than the dent strains. Columbus and his followers landed in countries where flint strains were widely grown. Consequently, flint maize probably was the type first seen by Europeans.

Sweet corn is characterized by a translucent, horny appearance when immature, and a wrinkled condition when dry. It is grown primarily in the United States. The ears are picked green and used for canning and table use. Sweet corn differs from dent by only one recessive gene which prevents the conversion of some of the sugar into starch. The main region of sweet corn cultivation used to be in the northern half of the United States. However, a considerable quantity of sweet corn is now being grown as a winter crop in the southern part of the United States.

Flour maize is somewhat similar to flint maize in plant and ear characteristics. The kernels are composed largely of soft starch and have little or no dent. Flour maize has been widely grown in the drier sections of the United States, and in some areas in South America and South Africa. It is one of the oldest types of maize, and is frequently found in graves of the ancient Aztecs and Incas. American Indians ground the kernels for flour because of their softness.

Popcorn is an extreme form of flint with the endosperm containing only a small proportion of soft starch. The cultivation and use of popcorn is almost entirely restricted to the New World. It is a relatively minor crop compared with dent maize. About 0.1 percent of the total maize acreage of the United States is planted to popcorn. The crop is used primarily for human consumption as freshly popped corn and is the basis of popcorn confections. The ability to pop seems to be conditioned by the relative proportion of horny endosperm where the starch grains are embedded in a tough, elastic colloidal material which confines and resists the steam pressure generated within the granule upon heating until it reaches explosive force.

Waxy corn is so named because of the somewhat waxy appearance of the kernels. Waxy starch is composed entirely of the branched molecular form, amylopectin, whereas common maize starch is approximately 78 percent amylopectin and 22 percent amylose, the straight chain form. China was the original source of the waxy gene, but waxy mutations have since occurred in American dent strains. Waxy hybrids have been developed in the United States and are now being grown commercially on a small scale to produce a starch similar to tapioca starch.

Podcorn is an unusual type of maize, each kernel of which is enclosed in a pod or husk. The ear is also enclosed in husks, as are the other types of maize. Homozygous podcorn usually is highly self-sterile, and the ordinary type of podcorn is heterozygous. Podcorn is not being grown commercially, but is of considerable interest in studies of the origin of maize.

3. INHERITANCE IN MAIZE

More is known about the genetics of maize than of any other economic plant or animal. Unfortunately however, most of the characters studied have been recessive defects of little economic importance.

Rather complete summaries of inheritance in maize were published by Emerson, Beadle, and Fraser (1935) and by Hayes, Immer, and Smith (1955). The cytogenetics of maize was discussed by Rhoades (1955). A catalogue of genetic maize types together with an extensive bibliography was prepared by Weijer (1952).

Advantages of Maize for Cytogenetic Research

Maize is well suited for genetic research. The plant is easy to grow and is adapted to a wide range of environmental conditions. It has a large number of distinct hereditary variations. Selfing or crossing is simple and rapid. Hundreds of kernels may be obtained on an ear with a single pollination. Often these seeds may be studied as if they were large numbers of distinct individuals. The comparatively small number of relatively large chromosomes permit easy cytological study. Rates of mutations for specific genes may be measured.

Qualitative Inheritance

Most of the nearly 500 different genetic factors reported in maize have been qualitative in nature. It is relatively easy to separate qualitative characters, since discontinuous classes of segregates occur. Such characters are usually determined by single genes.

Genes responsible for the various characters in maize fall into ten linkage groups corresponding to the ten different chromosomes. In general the chromosomes are numbered in order of decreasing lengths from one to ten.

Figure 16 shows the linkage map of the ten chromosomes of maize. This map gives the approximate location of the genes. A description of the characters produced is given by Hayes, Immer, and Smith (1955).

Methods of determining inheritance include the use of linkage testers, trisomics, translocations, inversions, and B-type chromosomes.

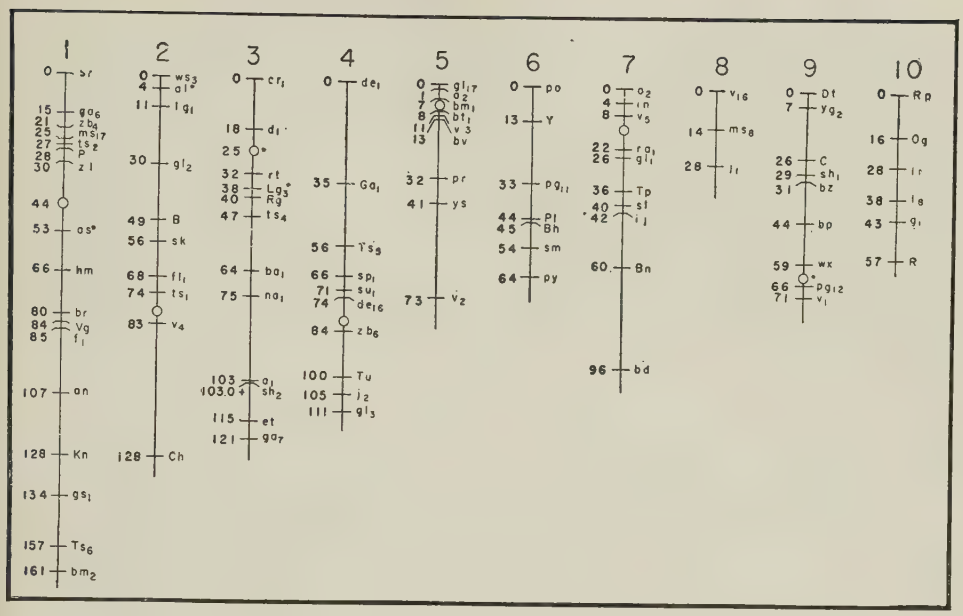


FIGURE 16 - *Linkage map of maize.*

(Courtesy, M. M. Rhoades)

A. *Centromere*
B. *Knob*
C. *Nucleolus.*

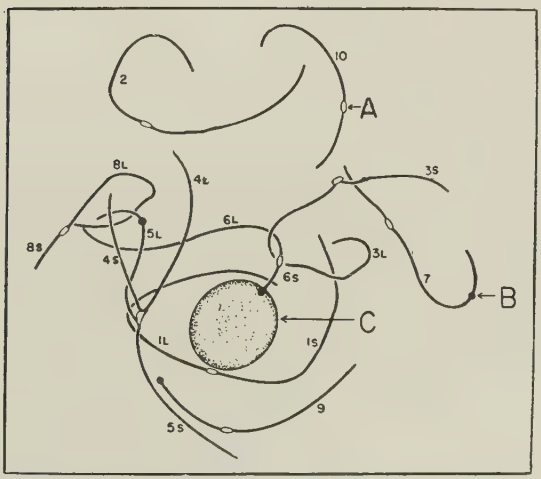


FIGURE 17. - *Camera lucida drawing of the pachytene chromosomes of maize.*

(Courtesy, M. M. Rhoades)

Quantitative Inheritance

Nilsson-Ehle (1908) and East (1910) pointed out that quantitative characters were controlled by multiple genes. These genes usually have small, nondominant, cumulative effects. The expression of quantitative characters is continuous, making separation into distinct classes very difficult. Yield and most economic characters are quantitative in their inheritance. The inheritance of quantitative characters is discussed in Chapters 10 to 15, inclusive. Hayes, Immer, and Smith (1955) also discuss the subject. There is no sharp line between qualitative and quantitative inheritance.

Chromosome Morphology

In discussing chromosome morphology, Rhoades (1955) pointed out that:

"The ten chromosomes comprising the monoploid or gametic number in maize are morphologically distinguishable by:

1. their relative lengths;
2. distinctive chromomere patterns;
3. deep-staining knobs in characteristic positions;
4. location of the centromere (determining arm ratios);
5. the degree of heteropycnosis in the chromomeres adjacent to the centromeres.

"These diagnostic features are most clearly evident at pachynema when the chromosomes are found as elongated paired threads; it is this stage which has been so widely used in cytogenetic studies."

A camera lucida drawing of the pachytene chromosomes of maize is shown in Figure 17.

Many Genes Have Been Studied

Rhoades and McClintock (1935) pointed out that:

"Genetic characters in maize show great diversity of effects but can be roughly classified into three groups on the basis of the type of tissue affected:

1. sporophytic characters (2n tissue);
2. gametophytic characters (1n tissue);
3. endosperm and aleurone characters (3n tissue)."

Rhoades (1955) stated that:

"Mutations have been found which affect aleurone, plant, pericarp, plumule, scutellum and endosperm colors, endosperm composition and development, plant height, chlorophyll formation (nearly 200 of these), structure of ear, tassel, leaf, and culm, modification of male and female inflorescences, carbohydrate metabolism, disease resistance, pollen and ovule abortion, pollen tube growth, etc.

Some of the more interesting genes to the cytogeneticist are those controlling chromosome behavior and specific stages of mitosis. Among these is the asynaptic gene which affects meiotic pairing, the sticky gene which causes the chromosomes to stick together as a confluent mass at metaphase and which produces an increased frequency of chromosomal aberrations and of mutations, and the polymitotic gene which induces the haploid nuclei of each quartet of spores to undergo a series of divisions in which the chromosomes pass undivided to one pole or the other, resulting in nuclei with less than the haploid number.

There are genes which cause a failure of cytokinesis, one which affects the shape of the achromatic figure, one which controls chromosome coiling and produces a high percentage of unreduced megaspores, and one which suppresses the onset of meiosis in both male and female flowers.

It is evident that genes not only determine the development of the plant as a whole but that the chromosomes themselves, which carry the genes, are also under genic control. Finally, there are genes which determine the mutational events at other loci and genes which induce irreversible changes in cytoplasmic components.

There are relatively few dominant mutants; most of the mutant characters in maize are controlled by simple recessive genes and appear in monohybrid ratios. Some of the best analyzed genetic situations, however, involve the complementary interaction of a number of genes; among these are plant, aleurone, and scutellum color. Although inheritance in maize is prevailingly at the diploid level, there are 18 cases of duplicate factor, 2 of triplicate factor, and 1 of quadruplicate factor inheritance."

Number of Genes

Various ways of estimating the total number of pairs of genes in certain species were discussed by Lush (1937). One type of evidence is the number of genes actually found by genetic studies. For example, more than 400 genes each have been reported in maize and *Drosophila melanogaster*, and 300 in snapdragons. Lush pointed out that this type of evidence has limitations. For example, only genes with major effects can be readily identified. Genes with minor effects may be grouped together as modifying factors. Many new genes may not be reported unless the effect is very unusual. The number of genes reported to date must be much less than the actual number that are present.

Cytology provides a second kind of evidence. About 2,650 distinct bands are present on the chromosomes in the salivary glands of Drosophila. Each band may be a separate gene. However, there may be several genes in some bands. The cytology of many plants, birds, and mammals

is difficult, limiting the value of this method of estimating the number of genes.

A third kind of evidence mentioned by Lush might be termed " indirect reasoning ". An example would be attempts to estimate the number of genes from the rate of mutations. Experiments of quantitative inheritance provide some evidence for estimating the minimum number of genes expressing their effects. " Student " (1934) estimated that at least 20 to 40, possibly 200 to 400, genes were involved in the Illinois High Oil selection experiment. Usually the number of genes estimated from quantitative inheritance data is too low.

Gene Structure

After discussing gene structure and gene function, Beadle (1955) concluded that:

" A consideration of available evidence suggests that the primary genetic material of many organisms is desoxyribonucleic acid (DNA). The polynucleotide chains of this material seem to consist of successive segments of perhaps several hundred nucleotides, each segment constituting a functional unit that serves to direct the specificity of a macromolecule, such as a protein. In viruses and bacteria, evidence from recombination studies indicates that modifications can occur at different levels within such a unit. It is possible that the so-called pseudoalleles of higher forms represent a similar situation.

" The question of whether nonspecific material — for example, the calcium-magnesium bridges that Mazia assumes to hold segments of chromatin together — separates one functional unit from another cannot be given a final answer at present. Evidence from studies of rII mutants of the T_2 bacterial virus, and of transduction, hints that the minimum unit of recombination, structural rearrangement, and mutation may be a single nucleotide."

Gene Action

Gene action is a complex phenomenon that is subject to several theories. It is difficult to devise experiments that would definitely answer these problems.

Brief explanations of several types of gene action were provided by Smith (1944):

" Interaction — gene action of such a nature that a certain gene substitution acts differently in combination with one genotypic background than with another. This definition is intentionally limited in scope and is essentially statistical when applied to quantitative data. The term is used frequently in genetics in the more general sense that the expression of certain (or all) characters is the end product of the combined action, i. e., interaction, of several or all of the genes of the genotype; however, as a rule, it is in the more restricted meaning, as defined above that the word ' interaction ' has been used in publications on quantitative inheritance.

Arithmetic action — each gene substitution adds or subtracts its contribution to that of the residual genotype. If the absolute amount added to the phenotype is the same regardless of the other genes present the gene in question would be considered as having independent arithmetic action.

Additive action — arithmetically accumulative and usually implying lack of interaction.

Geometric action — each gene substitution multiplies or divides the residual genotypic value by a certain amount. The absolute phenotypic contribution of the gene would vary according to the magnitude of the residual genotype, but if it acts as a fixed multiplier the gene would be considered independent and geometric in action."

Criteria for distinguishing between the results of geometric versus arithmetic gene action were published by Charles and Smith (1939).

	Geometric gene action is indicated if:	*Arithmetic gene action is indicated if:*
F_1 average is:	geometric mean of parent averages	
F_2 average is:	not much larger than F_1	midway between F_1 and midvalue of parent averages
Small backcross average is:	geometric mean of F_2 and small parent averages	midway between F_1 and small parent averages
Large backcross average is:	geometric mean of F_2 and large parent averages	midway between F_1 and large parent averages

Smith (1944) believes that skewness in the frequency distribution of measurements of quantity may be due to:

1. dominance;
2. the nature of gene action;
3. physiological limits to phenotypic expression;
4. interactions of various sorts;
5. metrical bias.

4. HETEROSIS

Heterosis is the phenomenon in which the cross of two stocks produces a hybrid which is superior in size, yield, or general vigor. Some workers define heterosis as the increased vigor of the F_1 over the mean of the two parents, while others consider it the increased vigor of the F_1 over the better parent. Shull (1914) suggested that this phenomenon be called heterosis. The term is a contraction of "stimulus of heterozygosis".

East (1936) believed that heterosis was best described by the term "hybrid vigor". Whaley (1944) pointed out that "heterosis" originally referred to the developmental stimulation resulting, by whatever mechanism, from the union of definite gametes. "Hybrid vigor" denotes the manifest effects of heterosis. Many workers use the two terms synonymously.

Occurrence and Manifestation

Heterosis has been recognized for at least two hundred and fifty years (Whaley, 1944). It is a widespread phenomenon in the plant and animal world, and has been observed both in self-fertilized and cross-fertilized plants.

Heterosis results in a general stimulus to the hybrid plant and affects it in a variety of ways. It often results in increased yield, earlier maturity, greater resistance to insects and diseases, taller plants, larger number and weight of fruit, increase in size or number of parts or in other external or internal characteristics. East (1936) stated that the effect of heterosis on the plant was similar to that obtained by the addition of balanced fertilizer to the soil, or of feeding a more adequate and more complete diet to the animal.

Whaley (1944) prefers the concept of the hybrid as being normal and the inbred parents as being inferior. Individual hybrid maize plants are not superior to the best plants of the open-pollinated varieties. Heterosis appears to increase the general metabolic efficiency of the hybrid plant.

Jones (1952) pointed out that:

"Heterosis has two general modes of expression. In one, there is an increase in size or number of parts. This is usually the result of a greater number of cells and a faster rate of cell division and cell activities. This results in an

improvement in general well-being of the organism similar to the result of being placed in a more favorable environment. A somewhat different manifestation of heterosis is an increase in biological efficiency, such as reproductive rate and survival ability. This may even be shown with a reduction in productiveness as measured by economic characters. There may also be a reduction in both growth and survival ability."

Importance and Utilization

Heterosis expresses itself primarily in the F_1 plants raised from seed. Therefore, it is necessary to repeat the cross for each crop. The importance and utilization of heterosis depend upon increased yields, the acquirement of other desired agronomic characters, ease of hybridization, or a low cost of seed production. The maize plant meets these qualifications in an unusual manner.

Hybrid maize depends upon heterosis. The United States annually receives increased yields of at least 750 million bushels through the use of hybrids. The utilization of hybrid maize in 15 European and Mediterranean countries in 1955 increased production in these countries by 844,900 tons with a valuation of over 67 million dollars (Table 5, page 20).

Ashton (1946) discussed the use of heterosis in the production of many crops. Hybrid onions, sorghum, alfalfa, sugar beet, tomatoes, watermelons, and ornamentals were discussed by Haber (1955). Other hybrids include forage crop and grasses, sunflowers, squashes, cucumbers and eggplants.

The classic example of heterosis in the animal world is the mule. Poultry and swine hybrids are other economic applications of this universal phenomenon with animals. Other possibilities include sheep, dairy and beef cattle.

Heterosis is of considerable interest in the study of developmental genetics. It is a phase of quantitative inheritance. East (1936) believed that the inheritance of quantitative characters may be the key to the explanation of heterosis. Smith (1944) reviewed the relation of heterosis and the inheritance of quantitative characters of plants.

Physiological Explanations

Various genetical and physiological theories have been advanced to explain heterosis. No one explanation is fully acceptable.

Shull (1909, 1914) gave a non-Mendelian, physiological-stimulation explanation of heterosis as follows:

"In other words, hybridity itself — the union of unlike elements, the state of being heterozygous — has, according to my view, a stimulating effect upon the physiological activities of the organism."

Ashby (1930, 1932, 1936a, 1936b, 1937) suggested that heterosis is due to the maintenance of the initial advantage in the embryo size and not to an acceleration of metabolic processes. Lindstrom (1935) eliminated the initial advantage of F_1 plants by removing the tops of F_1 seedling plants above their growing points and still found the manifestation of heterosis. Engledow and Pal (1934), East (1936), and Hatcher (1939, 1940) mentioned cases where no initial advantage of embryo size was available and yet heterosis was manifested by the F_1 hybrid plant. They concluded that embryo size has little relation to heterosis. East (1936) concluded that seed size or the size of any part of the seed cannot be the cause of heterosis.

Genetical Theories

East and Hayes (1912) attributed the vigor of the F_1 to its heterozygous condition. Thus the greater the number of genes in which a plant is heterozygous, the greater its heterosis. For example, a hybrid with the genetic constitution of AaBbCcDd would be more vigorous than another hybrid with the genetic constitution of AABBccDd. Theoretically, it would be impossible to obtain an inbred line as vigorous as the F_1 hybrids if this heterozygosity theory was responsible for heterosis. Diversity of germ plasm definitely affects the degree of heterosis.

The cumulative interaction of many favorable dominant or partially dominant linked-vigor genes is a widely accepted theory. It assumes that, in general, dominant factors contributed by each parent of the hybrid are desirable and recessive factors are harmful. Thus a hybrid is more vigorous than its parents because it has more dominant factors than recessive factors (Jones, 1917). The suggestion that hybrid vigor was due to the action of favorable dominants was proposed by Keeble and Pellew (1910) and Bruce (1910). Emerson and East (1913) pointed out that the F_2 should show an unsymmetrical distribution for the characters involved instead of the usual smooth curve. East and Hayes (1912) and Shull (1911a) objected to the theory because it should be possible to obtain vigorous inbred lines, whereas such had not been found. Collins (1921) showed that skewness would not occur in an ordinary-sized population. Jones (1917) explained that the failure to obtain skewness and recover inbred lines as vigorous as hybrids could be explained by linkage between favorable and unfavorable genes.

A type of intra-allelic action with dominance lacking was proposed by East (1936). Richey (1950) pointed out that East's "hypothesis involves a series of alleles at locus A, for example, such as A^1, A^2, A^3, A^4. Each allele of higher order is assumed to have a positive action function,

diverging further and further from that of A^1. Thus A^1A^4 would have greater physiologic efficiency than A^1A^2 ".

Complementary genes produce an effect which is different from that of any of them separately. Complementary action of alleles at a single locus has been proposed as a basis for heterosis. Singleton (1943) and Jones (1945) reported mutants whose hybrids showed vigor when crossed with the parent strains. These phenomena have been interpreted as " inter-allelic interaction ".

East (1936) believed that the heterozygote is superior to either homozygote. Fisher (1918), discussed this concept as " superdominance ". The superiority of the heterozygote, Aa, over either homozygote, AA or aa, was defined as " overdominance " by Hull (1945). Selection of both parents for growth vigor would be undesirable if heterosis is due to overdominance.

Minor deleterious recessive genes which may occur in large numbers with small individual effects might suppress the effect of heterosis [Garber and Rowley (1927), Mangelsdorf (1928), Wentz and Goodsell (1929), and Woodworth (1931)].

Deleterious recessives might inhibit full activation of desirable growth genes. The harmful effect of a homozygous, deleterious recessive gene might be countered by the introduction of its dominant allel.

Vigor, yield and most characters of economic importance in maize are quantitative in nature and controlled by a large number of genes. These genes may differ greatly in their effects. Gene action may be arithmetic, additive, or geometric. Degree of dominance, epistasis, and genotype-environmental interactions add to the complexity of the problem of explaining the phenomenon of heterosis. Fortunately, heterosis may be utilized effectively in spite of our ignorance.

5. MODIFYING GERM PLASM

Germ plasm is the portion of the cell protoplasm which determines the character of the species and is the physical basis of hereditary transmission. The possibility of influencing or directing the hereditable variability of organisms has been an objective of man through the centuries. Germ plasm may be modified by changes in the chromosomes or genes or both.

Sudden discontinuous, random, inherited variations are called mutations. A gene mutation is a sudden change in a single gene, and the individual showing the change is referred to as a mutant. Variation may also be caused by chromosome alterations involving more than single genes, such as haploidy, polyploidy, or heteroploidy. Variation may be due to changes in number or arrangement of the genes through duplication, deficiency, translocation, or inversion.

The mutation process is considered to be the prime source of evolutionary materials in spite of the fact that most mutations that arise are deleterious. Variations, however, may be due to other causes. For example, hybridization, segregation, crossing over, or the release of a gene from a balanced lethal may result in new recombinations.

Chromosomal Aberrations

The normal condition of the chromosomal apparatus in any strain, variety, or species is one in which:

1. The number of chromosomes is constant.
2. Every chromosome carries a definite set of genes.
3. The genes within each chromosome are arranged in a constant linear series.

Any deviation from the above regularities constitutes a chromosomal aberration (Dobzhansky, 1936).

Chromosome aberrations involve changes in chromosome numbers, and those which alter the number or arrangement of genes within

a chromosome (Figures 16 and 17, page 37). The following classification of chromosomal aberrations was published by Sinnott, Dunn, and Dobzhansky (1950):

1. *Changes in the number of chromosomes*

   (*a*) Changes involving entire sets; n = basic or monoploid number:

   (*i*) Haploidy (n): each chromosome represented singly.

   (*ii*) Polyploidy: each chromosome represented by more than two homologues. Triploidy (3n); tetraploidy (4n); pentaploidy (5n); etc. An autopolyploid is one derived by chromosome multiplication from a single diploid, so that the homologues come from the same source as in pure strains or homozygotes. An allopolyploid is one derived from a hybrid between two diploids, so that the homologues come from different sources.

   (*b*) Changes involving the numbers of chromosomes in a set (heteroploidy):

   (*i*) Monosomics represent the loss of one chromosome from one set. Where this occurs in the diploid, the chromosome complement is 2n — 1.

   (*ii*) Polysomics represent the addition of one or more chro mosomes to one set. Trisomic = 2n + 1, tetrasomics = 2n + 2, etc.

   (*iii*) Nullisomics represent the loss of both chromosomes of a pair.

2. *Changes in the number or arrangement of gene loci within a chromosome*

   (*a*) In number:

   (*i*) Deficiency or deletion-loss of one or more genes.

   (*ii*) Duplication-addition of one or more genes, as a result of which the organism carries the same gene repeatedly in its haploid-chromosome complement.

   (*b*) In arrangement:

   (*i*) Translocation, or segmental interchange-exchange of parts between nonhomologous chromosomes to form two new chromosomes. For example, if the original chromosomes were ABCDEF and GHIJKL, the new ones may be ABCJKL and GHIDEF.

   (*ii*) Inversion. Within a chromosome, a block of genes may rotate by 180 degrees. For example, a chromosome with genes in the order of ABCDEFG may change to AEDCBFG."

Frequency of Spontaneous Mutations

Different genes vary in their mutability. Stadler (1942) determined the frequency of mutation of eight genes in maize. He pointed out that:

"It is feasible with maize to determine at least the order of magnitude of mutation rates among unselected genes by a technique which is not unduly laborious. There are several gene-determined characters in maize which are expressed in the endosperm, so that the examination of seeds on an ear suffices to determine the genotype of several hundred individuals. If a plant homozygous for a dominant allele of one of these genes is pollinated by the recessive form, the seeds of the ear produced are heterozygous and show the dominant character. Now if any one of these seeds carries a recessive allele which has arisen by mutation from the dominant, it will show the recessive character, and the plant produced by this seed may be tested genetically to determine whether the change was due to mutation. This may be done simultaneously with a number of dominant genes determining endosperm characters. The plants may be grown in an isolated field with detasseling of the cultures used as female parents, so that hand pollination is not required and progenies as large as desired for examination may easily be produced. Since the dominant allele is present in the female parent, pollen contamination cannot give seeds of the type which would result from recessive mutation.

A trial of this sort was made several years ago with eight genes affecting endosperm characters. These were included in different combinations so selected as to avoid characters of conflicting expression. None of the eight genes had previously been known to mutate. The apparent mutations observed on the F_1 ears were all tested by back-crossing to the recessive stocks."

The results were as follows:

Gene	*Number of gametes tested*	*Number of mutations*	*Frequency per million gametes*
R	554,786	273	492
I	265,391	28	106
Pr	647,102	7	11
Su	1,678,736	4	2
C	426,923	1	2
Y	1,745,280	4	2
Sh	2,469,285	3	1
Wx	1,503,744	0	0

Induction of Mutations

Mutations may occur spontaneously or be produced by induction. H. J. Muller, in Texas, and L. J. Stadler, in Missouri, pioneered in testing the effects of X-rays on animal and plant materials, and found that the mutation rate could be greatly increased. Mutations in plants have been induced by treatment of pollen, young embryos, or seeds, by X-ray, ultraviolet ray, radium, temperature, electricity, mustard gas, chemicals, gamma radiation, and aging of seed.

Value of Mutations

Most mutations appear to be deleterious or of little economic value. In a recent review, Singleton (1956) pointed out that mutation breeding had developed some desirable strains of plants.

Singleton (1956) has devoted considerable time and effort to the study of chronic or continuous gamma radiation on mutation rate. This was accomplished by using a radioactive source of Co60. The Co60 source was set up in the middle of a field and plants grown in a circle around it.

Singleton's experiments have demonstrated that mutations can be induced most efficiently by subjecting the maize plants to a fairly high radiation for a short period, provided this period is a sensitive one. For maize, this occurs about one week prior to pollen shedding, but definitely after meiosis, which is the pollen-sensitive period. Since the pollen is so easily destroyed when radiation is applied at meiosis, it is necessary to get beyond meiosis before putting the plants in the radiation field. For maximum efficiency in inducing mutations, plants should not be grown in the radiation field but moved in for a short time only.

PART II

Breeding and Evaluation

6. EVOLUTION OF MAIZE BREEDING METHODS

Maize breeding involves the systematic improvement of the crop by controlling the parentage of the seed. The breeder discerns differences of importance in the available plant material and selects and increases the more desirable types. Maize breeding may be grouped into four general methods:

1. mass selection;
2. ear-to-row selection;
3. varietal hybridization;
4. hybrid maize.

The first two methods utilize selection, and the latter two methods involve hybridization and selection. Four pioneers who suggested or utilized one or more of these four methods of maize breeding are James L. Reid, C. G. Hopkins, W. J. Beal, and G. H. Shull (Figure 18). The older methods of maize improvement have been reviewed by Richey (1947, 1950), Jenkins (1937), and Hayes and Immer (1942). Consequently, these methods will receive only a brief review here.

Mass Selection

Mass selection is the oldest method of maize improvement. It consists of selecting desirable ears from the better plants and planting the selected seed *en masse*. Since maize is almost completely cross fertilized, the breeding material is a complex mixture of hybrids, and selection results in a shifting of the average instead of a true fixation of type. Success in mass selection depends largely on the accuracy of selecting the desired types. Most of the open-pollinated varieties in the United States were developed by mass selection. The varieties recommended in the United States were listed by Jenkins (1937).

The history of Reid Yellow Dent is a typical example of the procedure involved in developing open-pollinated varieties (Jugenheimer, 1955b):

" The story of Reid Yellow Dent maize started in 1846 when Robert Reid, father of James, moved from Ohio to Delavan, Illinois. Like most pioneers, the Reid family brought their seed with them in their covered wagon. This variety was known in Brown County, Ohio, as the Gordon Hopkins strain.

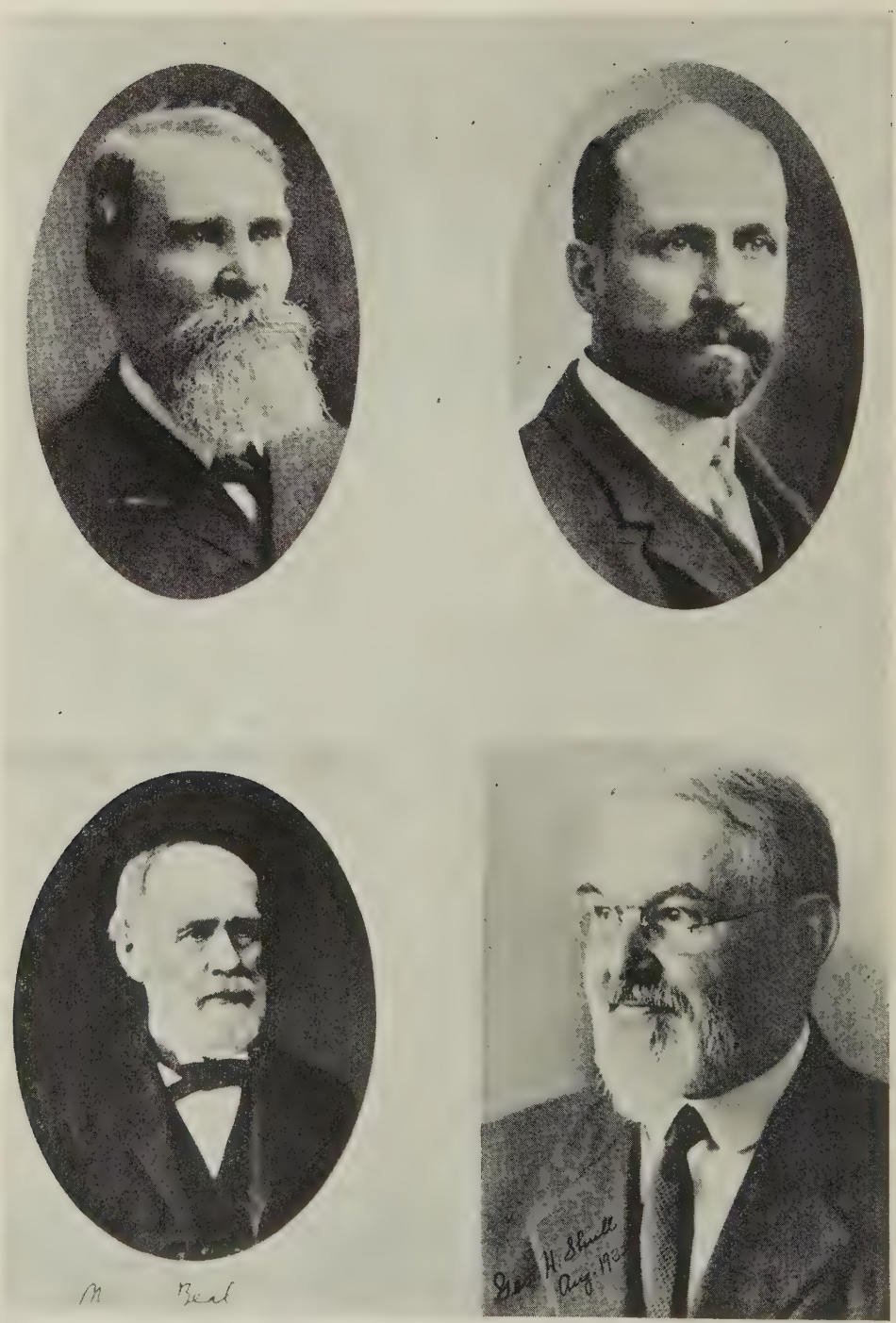


FIGURE 18. - *Four pioneer maize breeders.* (*James L. Reid,* upper left; *C. G. Hopkins,* upper right; *W. J. Beal,* lower left; *G. H. Shull,* lower right).

The Reid family arrived in Delavan quite late in the spring, but the seed was soon planted on land prepared by Uncle Daniel Reid. The late planting, however, resulted in an immature crop. The better ears were selected for the next year's seed, but the stand of young plants was poor. Consequently, the missing hills were replanted with seed of a small local variety known as Little Yellow.

The cross-pollination of these diverse strains resulted in a hybrid stock of germ plasm. During the next 20 years, James Reid's father strove to develop a strain of maize that was suited to the soil and climate of central Illinois.

A happy chance led to planting Gordon Hopkins and Little Yellow maize in the same field. It was equally fortunate that the Reids possessed the ability to put the resulting seed mixture through a rigorous selection process. Out of this combination of happenings came a strain which has served as a major source material for present-day hybrids.

James L. Reid left the home fields and started farming for himself in 1867. Ten years later, he grew a field of maize, using his father's strain, which yielded 125 bushels an acre, when the average yield in Illinois was only 27 bushels an acre. This remarkable crop was produced without modern fertilizers or special cultural methods.

The development of Reid Yellow Dent is an example of the effective use of selection. James took the basic materials he found in his father's field and fashioned a world-famous maize. He was convinced that his father had blended the elements needed for a better variety. He believed that the perfection of this strain was primarily a work of selection.

James Reid never planted his crop in a field which was exposed to pollen from the fields of his neighbors. He carefully protected its purity, even though it required giving seed to his neighbors for planting their fields.

Because of its consistent winnings at shows, wide adaptation, excellent field performance, and fine feeding qualities, the usage of Reid Yellow Dent continued to increase. The wide farmer acceptance of this variety led many breeders to develop their own strains of Reid Yellow Dent.

Surveys indicate that Reid's and selected strains of this variety were grown on about three fourths of the maize acreage in the Corn Belt over a period of at least 50 years. In 1937, 27 years after Mr. Reid's death, Reid Yellow Dent variety still was recommended by experiment stations in 21 different states (Jenkins, 1937).

Many inbred lines used for hybrids were developed from strains of Reid Yellow Dent by breeders in at least a dozen states. One of these inbred lines, WF9, was developed from the Wilson Farm strain of Reid Yellow Dent. This inbred is one parent of about half of all the hybrid seed ever produced. Two popular single crosses. WF9 × 38-11 and WF9 × Hy, resemble Reid Yellow Dent in appearance. Probably half of all the hybrid seed in the Corn Belt is grown on these two seed parents.

A bronze tablet has been placed on the Illinois farm where Robert and James L. Reid developed this great variety of maize. In the future, all may read the tribute appearing on the memorial tablet which was dedicated on September 10, 1955."

Many experiments have been conducted to determine the relationship between various plant and ear characters, and yield. In the United States, long, smooth, heavy ears with less than average kernel row number produced higher yields than the contrasting types. Open-pollinated varieties of maize differ considerably in many characteristics. This indicates that maize breeders differed considerably in their ideas as to

what constituted the ideal type. Various score cards were developed to aid in judging samples at shows. Some workers learned, however, that there was little correlation between performance and placing in a show. In fact, it was soon discovered that close selection of specific ear types resulted in inbreeding and actually reduced yields.

Mass selection, based on performance and quality, has resulted in the development and improvement of open-pollinated varieties. Experience has shown that yields may be maintained and even slightly increased if selection is not too close for a specific type. Selection has been rather effective in modifying maturity, plant and ear type, and chemical composition. The method, however, usually considers only the female parent, and improvement is slow and limited.

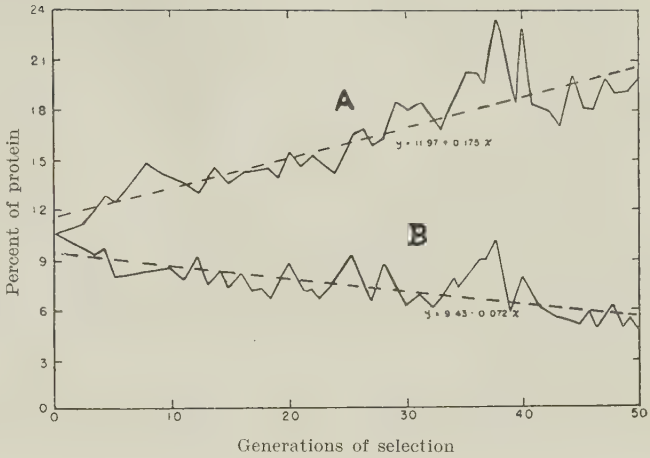
Ear-to-Row Selection

Ear-to-row selection was introduced by C. G. Hopkins (1899a, 1899b) at the Illinois Agricultural Experiment Station about 1896 in experiments to modify chemical composition and other agronomic factors in maize. The relative productiveness of different ears is evaluated by planting a portion of the seed from each ear in individual rows and determining the performance of the plots. Seed from the higher yielding ears is increased for commercial use.

The idea of utilizing progeny testing appealed to maize breeders in experiment stations and on farms. The earlier results appeared to be very promising, and many experiments were conducted on the procedure (Williams, 1907; Kiesselbach, 1922). The method became popular almost immediately, but the results proved to be rather disappointing.

The original ear-to-row procedures were modified by various investigators in order to overcome specific difficulties. Performance tests were improved by the use of check rows and replications. Inbreeding was lessened by detasseling plants in parts of rows and compositing seed from the detasseled plants of high yielding progenies. Seed of promising progenies was increased for farmer use.

The experiments started by Hopkins at the Illinois Station are classical examples of the effectiveness of selection for chemical composition. The results of 50 generations of selection for protein and oil in maize were reported by Woodworth, Leng, and Jugenheimer (1952). Selection for both high and low oil and high and low protein content was started in the Burr White variety in 1896. Ear-to-row selection was practised for the first 28 generations, while mass selection with intra-strain controlled cross pollination was employed for the last 22 generations.



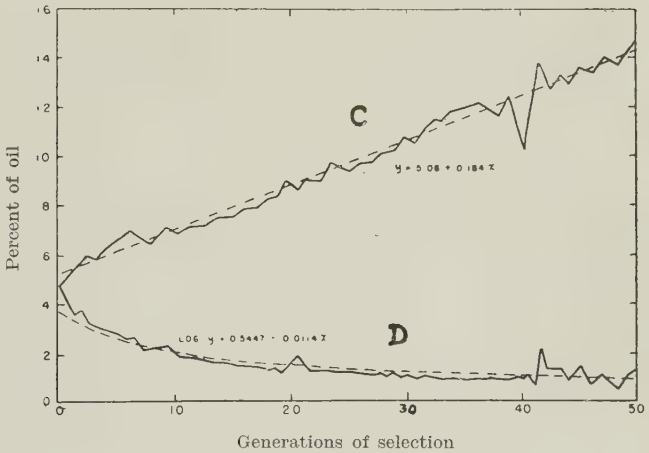


FIGURE 19. - *Effect of 50 generations of selection on protein and oil content of maize at the University of Illinois. Actual data indicated by solid lines; fitted trend lines are shown as broken lines.*

(Courtesy, Woodworth, Leng, and Jugenheimer, 1952)

A. *High protein*
B. *Low protein*
C. *High oil*
D. *Low oil*

The original Burr White variety in 1896 had a mean oil content of 4.7 percent and a mean protein content of 10.9 percent. After 50 generations of selection, the mean oil content of Illinois High Oil was 15.4 percent, that of Illinois Low Oil was 1.0 percent; the mean protein content of Illinois High Protein was 19.5 percent, that of Illinois Low Protein was 4.9 percent (Figure 19). Progress in the direction of selection is still being made in the Illinois High Oil and Illinois Low Protein strains, while little progress has been made in either Illinois Low Oil or Illinois High Protein in the last 15 to 20 generations of selection.

Variability, as measured by either the coefficient of variation or the Weinberg formula, has remained virtually unchanged in Illinois High Oil. The coefficient of variation of Illinois Low Oil has increased markedly, while the Weinberg constant has shown little change. Illinois

High Protein has shown an increase and Illinois Low Protein a decrease in both measures of variability as the result of selection.

Eight generations of random breeding were compared with regular selection in each of the four strains in the years 1934-1941. Average differences between the two breeding systems ranged from 0.22 percent in Illinois Low Oil to 1.49 percent in Illinois High Oil. All changes in the random-bred strains were in the direction of the original Burr White analysis. Two generations of reverse selection, begun in 1948, have indicated that Illinois High Oil, Illinois High Protein, and Illinois Low Protein may still possess considerable genetic variability. Virtually no change in the oil content of Illinois Low Oil has thus far been made by reverse selection.

The success of the Illinois oil and protein selection studies might be due to the following reasons:

1. Characters used can be accurately measured.
2. Selection was carried on for many generations.
3. Careful selections were made each year.
4. Inbreeding was lessened by the use of isolated plots and hand pollinations.

Smith and Brunson (1925) compared ear-to-row selection with mass selection. Seed of 990 selected ears was planted ear-to-row. Composited seed of these same ears was planted in an isolated plot and maintained by mass selection. Selection was for both high and low yield in the "pedigree" or ear-to-row type of selection. The Station strain of Reid Yellow Dent was used as a standard. The relative efficiency of ear-to-row versus mass selection from 1913-1922 is shown in Table 7. The high yielding strain maintained by ear-to-row selection yielded 110.4 percent of Reid Yellow Dent compared to 107.6 percent for the non-pedigree strain maintained by mass selection during the first five-year period. The low yielding strain developed by ear-to-row selection yielded 98.1 percent of Reid Yellow Dent. As an average of the second five-year period, the high yielding strain developed by the ear-to-row procedure yielded 108.3 percent of the check compared to 85.7 percent for the low yielding strain and 106.1 percent for the mass selection strain. As an average of the ten years, 1913-1922, the high yielding strain selected by the ear-to-row procedure averaged 62.3 bushels per acre compared to 60.9 for the mass selection strain. Selection for low yield by ear-to-row selection was more effective than selection for high yield. The authors concluded that the simpler method of mass selection was just as effective in improving yield as the more complicated method of continuous ear-to-row breeding. The difference between the high yield and the low yield strain was brought about primarily by a decrease in the low yield strain.

TABLE 7. — RELATIVE EFFICIENCY OF EAR-TO-ROW SELECTION VERSUS MASS SELECTION

Years	Type of selection			Reid Yellow Dent
	Nonpedigree (mass)	Pedigree (ear-to-row)		
		High yield	Low yield	
	Acre yields, bushels			
1913-1917	50.6	51.9	46.1	47.0
1918-1922	71.2	72.7	57.5	67.1
10-year average	60.9	62.3	51.8	57.0
	Percentage of Reid Yellow Dent			
1913-1917	107.6	110.4	98.1	100.0
1918-1922	106.1	108.3	85.7	100.0
10-year average	106.8	109.3	90.9	100.0

SOURCE: Smith and Brunson, 1925

Smith (1909) reported the effect of selection for ear height. At the end of six generations, ear height of the Illinois High Ear strain was 57.3 inches compared with 23.1 inches for the Illinois Low Ear Strain. Unpublished data from the Illinois Station show a difference of 74.8 inches between Illinois High Ear and Illinois Low Ear strains at the end of the thirteenth year. Selection for high ears resulted in obtaining plants having longer internodes and which bore their ears at a higher node.

Probable reasons why ear-to-row selection for yield was disappointing were that:

1. Field plot techniques used were inadequate for the accurate determination of yields.
2. The higher yielding progeny rows probably were hybrids of unknown parentage which did not breed true.
3. Continued ear-to-row selection resulted in inbreeding.

Ear-to-row selection, however, has been effective in modifying chemical composition and ear height, and useful in improving the yield of unadapted varieties. The conception of progeny testing was also an advance in maize breeding.

Varietal Hybridization

Varietal hybridization utilizes first generation crosses between open-pollinated varieties of maize as a means of obtaining larger yields. The American Indians probably utilized hybridization long before the coming of the white man. Their religious ceremonies resulted in semicontrolled mixing of types with different endosperm colors.

The older methods of maize improvement considered only the ear of the plant. H. S. Bidwell (1867) pointed out the importance of both pollen and ear selection in maize improvement. W. J. Beal also emphasized the importance of pollen selection about 1876. Beal (1880) crossed open-pollinated varieties of maize to increase yield. His varietal hybrids out-yielded their open-pollinated parents in three different years. Beal's results created considerable interest in varietal hybridization. Morrow and Gardner (1893) outlined a procedure for producing F_1 hybrid seed. Many other workers have investigated the possibilities of varietal hybridization.

The results obtained from varietal hybridization were rather conflicting. Richey (1922) summarized data from 244 comparisons. Of this number, 82 percent yielded more, and 18 percent yielded less than the average of the parents. Perhaps 10 percent yielded more than the better local varieties. In general, the highest yielding crosses involved high yielding parents which differed considerably in ear type. Crosses between flint or flour types with dent usually produced increased yields. Dent by dent crosses exhibited less superiority. Some varietal hybrids have performed well in the Netherlands, Yugoslavia, and Mexico.

Varietal hybrids were never used commercially on an extensive acreage in the United States because:

1. The results were inconsistent.
2. The method was more complicated than mass selection.
3. Newly crossed seed had to be produced each year.

The method was an advance in the principles of maize breeding because it considered both parents, avoided inbreeding, and often increased yields.

Hybrid Maize

Hybrid maize utilizes first generation crosses among inbred lines. Publication of Shull's results in 1908 and 1909 marks the practical beginning of hybrid maize breeding. Shull (1908) concluded:

"1. In an ordinary field of corn the individuals are generally very complex hybrids.

2. The deterioration which takes place as a result of self-fertilization is due to the gradual reduction of the strain to a homozygous condition.

3. The object of the corn breeder should not be to find the best pure line, but to find and maintain the best hybrid combination."

Shull (1909) was the first to report increased yields from F_1 crosses between inbred lines. He outlined a method of breeding to utilize this increased vigor and yield which considered:

1. finding the best inbred lines;
2. the practical use of the inbred lines in the production of seed.

After nearly a half-century, the suggestions made by Shull (1909) are still practical guides to maize breeders:

"(1) In finding the best pure-lines it will be necessary to make as many self-fertilizations as practicable, and to continue these year after year until the homozygous state is nearly or quite attained. Then all possible crosses are to be made among these different pure strains and the F_1 plants coming from each such cross are to be grown in the form of an ear-to-row test, each row being the product of a different cross. These crossbred rows are then studied as to yield and the possession of other desirable qualities. One combination will be best suited for one purpose, another for another purpose. Thus, if the self-fertilized strains be designated by the letters of the alphabet, it may be found that the cross C × H will give 120 bushels per acre of high-protein corn, that F × L produces a similar yield of low-protein corn, that K × C gives the highest oil-content accompanied by high yield, and so on. Moreover, it seems not improbable that different combinations may be found to give the best results in different localities and on different types of soils. The exchange of pure-bred strains among the various experiment stations greatly increases the number of different possible hybrid combinations and facilitates the finding of the best combination for each locality and condition.

"(2) After having found the right pair of pure strains for the attainment of any desired result in the way of yield and quality, the method of producing seed-corn for the general crop is a very simple though somewhat costly process. Two isolated plots will be necessary, to which I may conveniently refer as Plot I and Plot II. In Plot I will be grown year after year only that pure strain which investigation has proved to be the best mother-strain for the attainment of the desired end. Thus, if it has been found, as in the example already cited, that cross C × H gives the desired result, Plot I will be occupied by Strain C. This will require no attention from the breeder's point of view except that any exceptionally vigorous or aberrant individuals should be eliminated, as such plants might be safely assumed to be the result of a foreign pollination. In Plot II, strain C and strain H are to be planted in alternate rows, and all of strain C is to be detasseled at the appropriate time. All the grain gathered from the detasseled rows will be seed corn for the general field crop, and that gathered from the tasseled rows will be purebred strain H to be used again the following year in the same way. Here again in pure strain H all exceptionally vigorous or aberrant individuals should be discarded as being probably due to the entrance of foreign pollen."

Wallace and Brown (1956) point out that:

"It is impossible to judge whether East or Shull made the greater contribution towards the development of modern hybrid corn. They were working independently, doing essentially the same things, and, in our belief, they probably deserve equal credit. As we pointed out earlier, East's influence on cornbreeders probably has been greater than that of Shull. This may have been due in part to his dynamic personality, but he also had the advantage of working with better breeding material than that used by Shull. Some of East's inbreds were actually used for a short time in commercial hybrids."

The work of Shull, East and co-workers resulted in creating considerable interest in the utilization of first generation hybrids between inbred lines. All inbred lines of dent maize so far developed are inferior to open-pollinated varieties in vigor and yield. Until such time as decidedly more productive lines are developed, the ultimate use of inbred lines in commercial maize growing is in the production of hybrids.

Several kinds of hybrids are possible, depending upon the number of inbred lines involved. The simplest hybrid, known as a single cross, is made by crossing two inbred lines. Shull's hybrids were single crosses. Single crossed seed, of necessity, is produced on inbred plants which are relatively poor producers of seed and pollen. This makes the cost of single crossed seed relatively great because the acre yield of seed is small. The high cost of seed was the principal reason why hybrid maize did not become popular immediately after Shull's reports.

Jones (1919, 1922) suggested the utilization of inbred lines in double cross combinations. This procedure eliminated the excessive seed costs as an important factor in production. A double cross hybrid is produced by combining two single crosses. Double crossed seed is produced on single crossed plants which are highly productive of quality seed. Single crossed plants likewise produce pollen abundantly. This makes possible a greater proportion of seed-producing rows to pollen rows in the crossing field. Furthermore, single crossed plants withstand adverse conditions much better than inbred plants, reducing the risk in seed production. All of these factors have an important bearing on the cost of producing seed and favor the use of double crosses. Most investigators in maize breeding agree that, with present inbred lines, the double cross is the most economically produced field maize hybrid.

7. DEVELOPMENT OF INBRED LINES

Hybrid maize is produced by crossing selected inbred lines. The obtaining or development of inbred lines, therefore, is the first requisite of a hybrid maize program. Inbred lines are relatively homozygous, pure breeding strains developed by controlled inbreeding and selection.

Early Inbreeding Studies

Darwin (1876) appears to have been the first investigator to conduct inbreeding experiments with maize. He found that self-fertilization reduced plant vigor and that the crossed maize plants were more vigorous than the self-fertilized plants. The Illinois Station conducted inbreeding experiments prior to 1900. McCleur (1892) reported that variety hybrids were made at the Illinois Station in 1889. He found that crossing usually increased vigor and yield. Inbreeding maize often resulted in partial sterility, deformity, and decreased vigor. Second generation hybrid seed usually was lower yielding than first generation seed. Morrow and Gardner (1893) and many others also reported increased yields from varietal hybrids. Shamel (1905) reported reduced yield in maize strains self-fertilized from 1898 to 1902.

In 1905, G. H. Shull and E. M. East started inbreeding maize independently. Shull (1908, 1909) working at Cold Spring Harbor, Long Island, New York, was interested in studying the inheritance of kernel row number. The experiments of East were started at the Illinois Agricultural Experiment Station and continued at the Connecticut Agricultural Experiment Station. East (1908, 1910) studied the effects of inbreeding and outbreeding. The superior performance of the crosses among inbred lines developed in connection with these inheritance studies led to the suggestion of a new method of maize breeding and ultimately to our present-day maize hybrids.

Jenkins (1937) reported on early inbreeding projects. These included the inbreeding studies of C. P. Hartley about 1900. Shamel at Illinois in 1905 apparently was the first to report yields of a cross between inbred

lines. He reported the yields of two inbreds which had been self-pollinated for three generations and of the first generation cross between them.

According to Jenkins (1937):

"Other inbreeding projects were those of G. N. Collins in the Bureau of Plant Industry, begun in 1908, and of E. S. Montgomery, of Nebraska Agricultural Experiment station, begun in 1909. In 1914, H. K. Hayes went from Connecticut, where he had been working with East, to the Minnesota Agricultural Experiment Station and began inbreeding corn there. In 1916, F. D. Richey and C. H. Kyle, of the Bureau of Plant Industry, and J. R. Holbert, of Bloomington, Illinois, began their inbreeding experiments. H. A. Wallace of Des Moines, Iowa, the first private breeder to inbreed corn, started his work in 1913, but did not go at it systematically until 1919."

Sources of Inbred Lines

Inbred lines may be developed from desirable open-pollinated varieties or hybrids. The choice of source material may depend on the status of the program. Open-pollinated varieties must be used when desirable hybrid material is not available. A list of the better open-pollinated varieties of maize in the United States was reported by Jenkins (1937). Seed of most of these varieties is limited or not available at the present time.

The National Research Council, Washington, D.C., U.S.A., is sponsoring a project on the collection and maintenance of aboriginal races of maize in the western hemisphere. Seed storage centers were established at Mexico City, Mexico; Mendellin, Colombia; and Piricicaba, Brazil. The material is being catalogued and described and is available to research workers. The North Central Regional Plant Introduction Station, Ames, Iowa, U.S.A., also is maintaining open-pollinated varieties of maize from many sections of the world.

Plans for the permanent maintenance of maize open-pollinated varieties from European and Mediterranean countries were made in 1955 at the Eighth FAO Hybrid Maize Meeting held in the Netherlands. The delegates recommended that national collections should be made as complete as possible and that individual governments should accept responsibility for maintaining them in a viable condition on a permanent basis.

In order to insure against the loss of varieties from causes beyond the control of the national stations, the entire maize collection will be maintained in duplicate on a regional basis. These four regional centers will be located in the Netherlands, Italy, Yugoslavia, and Egypt. The *Stazione Sperimentale di Maiscoltura*, (Experimental Station for Maize Culture) Bergamo, Italy, will function as a documentation and information center for regional co-ordination.

In 1956, the delegates at the Ninth FAO Hybrid Maize Meeting in Egypt suggested that countries distinguish between samples, strains

and varieties, and give consideration to bulking seed of material that originates from a single ecological and climatic area if the material is similar in maturity, vegetative growth, and ear and kernel characteristics. A form was prepared to ensure the uniform classification of collections.

In later stages of the program, hybrid material may be utilized as sources of new inbred lines. This hybrid material may include single crosses, top crosses, three-way crosses, double crosses, back crosses, or synthetics. Starting with the F_2 generation gives a wide choice of plants for selection. Top crosses involving inbred lines from the United States and European open-pollinated varieties appear to be desirable sources of germplasm for the development of inbred lines for European and Mediterranean countries. Care must be taken to ensure the maintenance of genetic diversity.

Genetic Diversity of Germ Plasm

Genetic diversity is an important factor in obtaining desirable hybrids. Inbred lines from unrelated sources are more likely to produce better hybrids than inbreds derived from the same or closely related varieties. U.S.13 is an excellent example of the value of genetic diversity and co-operative effort. This hybrid has given excellent performance in practically all sections of the world when grown in the proper range of maturity.

The inbreds involved in U.S.13 came from the breeding programs of several States. Hy was produced by the United States Department of Agriculture in co-operation with the Kansas and Illinois Agricultural Experiment Stations from Illinois High Yield. Illinois High Yield was developed by ear-to-row selection at the Illinois Station. L 317 was obtained by the United States Department of Agriculture in co-operation with the Iowa Agricultural Experiment Station from Lancaster Surecrop, an excellent open-pollinated variety from Pennsylvania. WF9 and 38-11 were developed by the United States Department of Agriculture in co-operation with the Purdue Agricultural Experiment Station from strains of Reid Yellow Dent.

Eckhardt and Bryan (1940) found that single crosses of widely different parentage produced the highest yielding double crosses. Wu (1939), Hayes and Johnson (1939), and Johnson and Hayes (1940) also obtained results which emphasized the value of genetic diversity of inbred lines when used in hybrids. Hayes and Immer (1942) state that:

> "Genetic diversity may be of as great value or greater value than combining ability."

Considerable effort is being devoted in several European countries to the development of flint × dent hybrids. Many of the flint inbreds

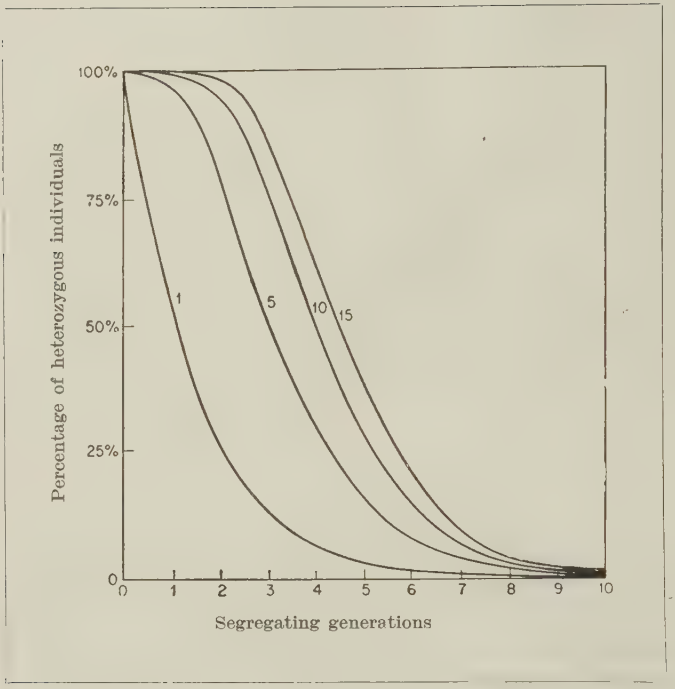


FIGURE 20. - *The percentages of heterozygous individuals in each selfed generation when the number of independently inherited factor pairs are 1, 5, 10 and 15. The percentage of heterozygosis in any selfed generation is given by the curve for one factor pair.*

(Courtesy, H. K. Hayes and F. R. Immer, 1942)

are being developed in Europe and the dent inbreds in the United States and Canada. Some of the hybrids involving these inbreds from diverse germ plasm have a high degree of heterosis. In general, flint inbreds contribute early maturity, good germination and early vigor, while productiveness, standability, large mature plant size, freedom from tillering, and resistance to smut (*Ustilago zeae*) are common desirable dent traits.

Anderson and Brown (1952) give archeological, historical, cytological, and genetical evidence that common dent maize of the United States Corn Belt originated primarily from the mixing of the Northern Flints and the Southern Dents. The Northern Flints and Southern Dents belong to widely different races of maize. The authors suggest that the diversity of germ plasm of these two races be considered in inbreeding programs. They believe that morphological characters of dents and flints, if carefully chosen, should be useful criteria for determining specific combining ability.

Intensity of Inbreeding

Most of the inbred lines involved in present-day hybrids were developed by self-pollination or sib-pollination. Self-pollination is the process of applying pollen of a plant to its own silks. Sib-pollination is the process of applying pollen of a plant to the silks of a sister plant. Self-pollination

FIGURE 21. - *Flowers of the maize plant.* (Left) *Tassel or male inflorescence;* (right) *Ear or female inflorescence.*

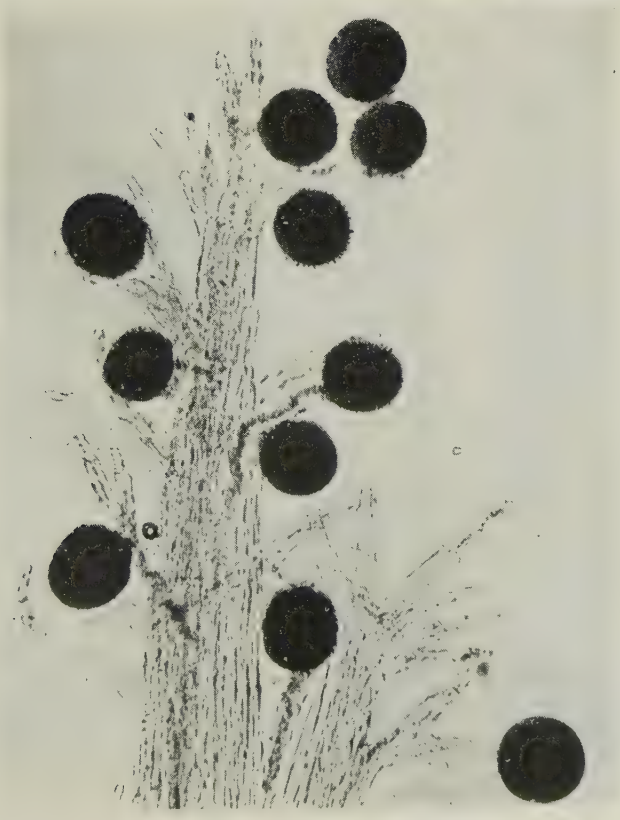


FIGURE 22. - *Pollen on silks (stigmas) of the maize plant.*

(Courtesy of O. J. Eigsti)

FIGURE 23. - *Tassel-bag method of making hand-pollinations.*

A. *Shoot must be bagged before silks emerge.*

B. *Cutting back the shoot usually encourages an even tuft of silks.*

C. *Semitransparent bag is pinched securely between the shoot and stalk to hold it in place.*

D. *Silks exposed to show about the right stage for pollinating.*

E. *Bag of heavy Kraft paper, with waterproof seams, is placed over the tassel and fastened with a paper clip.*

F. *Pollen is collected about 24 hours after bagging the tassel. Care must be exercised to prevent contamination.*

G. *Shoot bag is removed without touching or exposing the silks. Bottom of bag is flipped upwards, causing the pollen to fall upon the silks.*

H. *Tassel bag is pulled down over the shoot and fastened with a stapler or paper clip.*

approaches homozygosis approximately three times as rapidly as brother-sister mating. Jones (1918) and Hayes and Immer (1942) present graphs showing how rapidly self-fertilization leads to homozygosis (Figure 20).

Technique of Self-Pollination

Maize is a naturally cross-pollinated plant. It is necessary, therefore, to control pollination artificially to obtain a self-fertilized ear. Three general methods of making self-pollinations have been suggested:

1. tassel-bag;
2. bottle;
3. over-all.

In the tassel-bag and bottle methods, the uppermost ear shoots are covered with glassine or parchment bags before the silks emerge.

The tassel-bag method is the usual method of making pollinations. The tassel is covered with a 12-pound Kraft bag to collect uncontaminated pollen for use in making pollinations. The tassel usually appears shortly before the silks (stigmas) on the same plant and soon starts shedding pollen. It sheds pollen for three or four days, or even longer. Figure 21 shows a tassel, or male inflorescence, and a young ear, or female inflorescence, of the maize plant. Relative size of the pollen and silks is illustrated in Figure 22.

To obtain a self-fertilized ear, it is necessary to cover the ear shoot before any silks appear, collect pollen from the tassel, and artificially apply it to the silks. A bag, 3 × 8 inches or 3 ½ × 9 inches, made of glassine, parchment, or semi-transparent paper, is convenient to cover the ear shoot. Such a bag permits observation of the silks as they grow. The sides of the silks usually are receptive to pollen along their entire length, and they must not be exposed nor should unwanted pollen be allowed to sift down among them. Steps in the tassel-bag method of making hand-pollinations are shown in Figures 23a to 23h inclusive.

The tassel is covered with a large paper bag when the silks are an inch or two in length and the tassel has started to shed pollen. A 12-pound bag made of heavy Kraft paper, having the seams joined with waterproof glue, is satisfactory for this purpose. Two types of such bags are made: the flat or satchel-bottom type, and the pointed or square-bottom. The square-bottom type has proved to be the most satisfactory, since it sheds water more readily. A tassel bag in place is shown in Figure 23e. It should be left on about 24 hours and the pollen then collected. Corrugated paper clips may be used to fasten the tassel bags on the tassel. Edges should be placed together and the corners folded over and fastened around the neck of the tassel as tightly as possible. When the tassel bag is removed, care must be taken to avoid spilling the pollen.

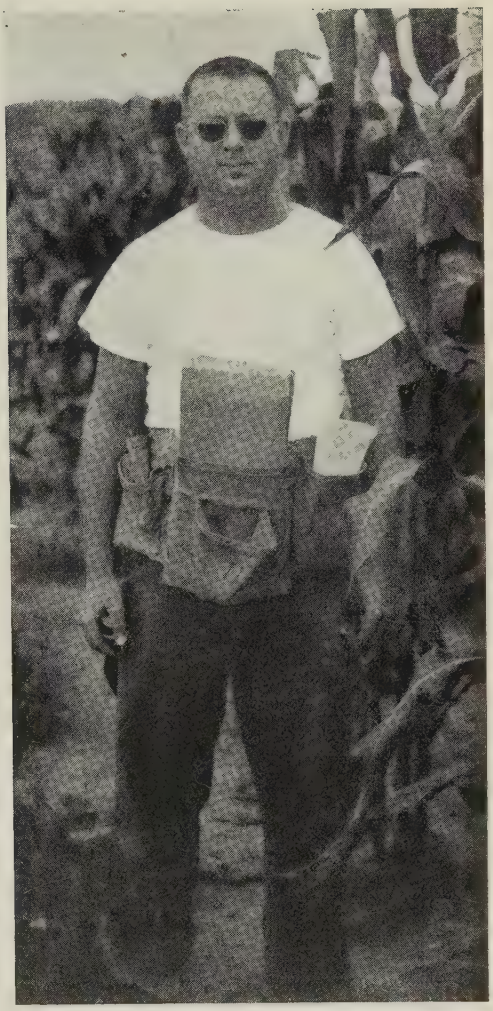


FIGURE 24. - *A desirable type of pollinating apron.*

FIGURE 25. - *Hand pollinations may be made with a pollen gun.*

Pollen should be applied to the silks in a manner that will not expose them to contamination from pollen of another plant during the operation. A convenient method is as follows: Fold the tassel bag about ⅓ of the distance from the bottom, holding it so that the pollen will remain in the bottom of the bag (Figure 23g). Slip the tassel bag over the shoot to be pollinated; reach up inside the bag and carefully remove the shoot bag without touching or exposing the silks. Pull the tassel bag down carefully with one edge of the bag between the shoot and the stalk.

Either break down the leaf and let the outer edge of the bag remain outside the leaf and shoot, or pull the outside edge of the bag between the shoot and the leaf sheath. Then flip the bottom of the bag upwards, spreading it open as it is lifted, and shake vigorously; this causes the pollen grains to fall upon the silks. Pull the two front edges of the bag around the stalk, fold them and fasten with a paper clip or stapler. This completes the pollination process. A completed pollination is shown in Figure 23h. A desirable type of pollinating apron is shown in Figure 24.

It is necessary to inspect the bags occasionally to make sure that the ear shoots do not grow through them and expose the silks while they are still receptive. The bag may be left on the ear until harvest.

The tassel-bag method may be used for crossing inbred lines, sister plants within lines, or hybrids. In crossing different parents, the pollen is taken from one parent and used on the silks of the other parent. Hand pollinations may also be made with a pollen gun (Figure 25).

The bottle method was suggested by Jenkins (1923). The ear shoots are covered with a transparent bag before the silks emerge. When the silks have emerged and the tassel is shedding pollen, the silks are cut back about ½ inch. The tassel is cut from the stalk and placed in a bottle of water directly above the silks. Tassel and silks are enclosed in a 12-pound Kraft paper bag. The water keeps the tassel alive until the silks emerge again, at which time pollination takes place. Jenkins found that a mild disinfectant in the water retarded the growth of micro-organisms and lengthened the life of the tassel. A solution of sodium bisulphite, 1:2,000, which must be fresh, proved to be satisfactory for this purpose. The tassels may be removed and the bottles collected 48 to 72 hours after pollination. The bottles may be used again for other pollinations. The various steps of the bottle method are illustrated in Figure 26. The bottle method is especially useful when pollinations need to be made in a wet, humid climate.

The over-all method of making pollinations was suggested by A. N. Hume (1941). This method utilizes a cloth bag which covers the entire plant. The bag is placed over the plant shortly before pollination. The leaves between the tassels and silks are removed in order to facilitate the dropping of pollen onto the silks. This method has been used very little.

FIGURE 26. - *Steps in the "bottle method" of pollinating:*

(Left) *The semitransparent glassine or parchment bag has been removed, the silks and tip of the ear shoot cut back and a bottle of water attached to the stalk just above the ear-bearing node.* (Right) *Completed pollination showing the shank of the tassel being inserted in the bottle of water.*

Results of Inbreeding

Inbreeding in maize results in a marked decrease in vigor and productivity. Reduction in vigor as a result of seven generations of self-pollination is shown in Figure 27. Theoretically, about one half of the total decrease in productivity from the open-pollinated plant to the pure line will occur in the first generation of selfing, one half of the remainder in the second generation, and so on until, finally, there is no further noticeable reduction. On the average, about 97 percent of this reduction in vigor occurs in the first five generations of selfing. Jones (1939) indicated that reduction in height usually ceased after five generations. He also found that reduction in yield usually ceased after 20 generations.

Inbreeding results in a rapid approach toward plant uniformity within any progeny or line. Difference from line to line, however, often are extreme. Practically all of the plants in one line may be strong, erect, disease-resistant or drought-resistant, while a neighboring line may have plants which are spindling, weak-rooted, badly infected with smut or ear rots, or which are susceptible to heat and drought.

Reasons for Inbreeding

The chief objective of inbreeding is to obtain pure breeding lines superior in combining ability. These are crossed for the production of maize hybrids. Crossing inbred lines may produce *good* or *poor* hybrids. When a desirable combination is found, however, it may be remade year after year without change by the use of the same pure-breeding inbred lines. The high degree of uniformity attained among the plants of an inbred line is present in the cross between two such lines. The crossed plants will all have the same heredity. If the parents contribute desirable genes for high yield, every plant will have the same high yielding capacity. If they contribute few genes for vigor and yield, every plant will be lacking in vigor and yield.

Inbreeding brings to light and makes possible the elimination of deleterious or inferior recessive characters, such as white or yellow seedlings which die as soon as the food material stored in the seed is used up, barren plants, dwarf plants, striped plants, and many other less extreme defects.

Rhoades and McClintock (1935) reported between 350 and 400 genetic characters in maize. Most of these are recessive defects. Under natural conditions, these characters are suppressed by the constant crossing of

FIGURE 27. - *Reduction in vigor as a result of seven generations of inbreeding.*
(Courtesy, Connecticut Agricultural Experiment Station)

maize. If these weaknesses are brought into expression by self-pollination, the lines which possess them are discarded and only the stronger lines are continued.

Experimental results indicate that the more vigorous lines tend to produce the better crosses and, from the standpoint of practical production, they are certainly much more desirable. By careful selection among large numbers of progenies, it is possible to get reasonably vigorous lines yielding perhaps one half as much as the original variety.

Importance and Basis of Selection

Rigid selection should be used to isolate pure-breeding lines superior in combining ability and with desirable phenotypes that can be readily propagated. The least desirable lines should be discarded early in the inbreeding period. The quality ears from the more desirable plants are selected each year for continuation of the inbred lines. Plants are selected on the basis of desired traits such as vigor, yield, standability, maturity, low ears, dark green chlorophyll, good tassels, grain quality, and resistance to diseases, insects, barren plants, broken shanks, and freedom from abnormalities. Selection is effective only for those characters which are inherited and which may be definitely classified in the line. Selection of lines prepotent for high yield must be based very largely on their performance in crosses.

Experience has shown that the isolation of good inbred lines requires the pollination and testing of a large number of plants. A large proportion of the inbred lines obtained through the inbreeding process are only average or mediocre. It is necessary, therefore, to test many lines in order to find an occasional desirable one.

Miscellaneous Considerations

Accuracy and careful work are primary considerations of a maize breeding program. All phases of the program should be carefully planned well in advance of the pollinating season. A map of the breeding plots should be prepared. Strains to be crossed should be planted near one another. Material that is to be used repeatedly can be planted in several places so that it will be more accessible. Often it is advisable to plant at two different times in order to spread the pollinating period and increase the chances of having a successful season.

It is advisable to put seed in separate envelopes for each row or plot. The envelopes should be labeled with the appropriate pedigree and plot numbers. Precautions should be taken to eliminate mixtures. Envelopes

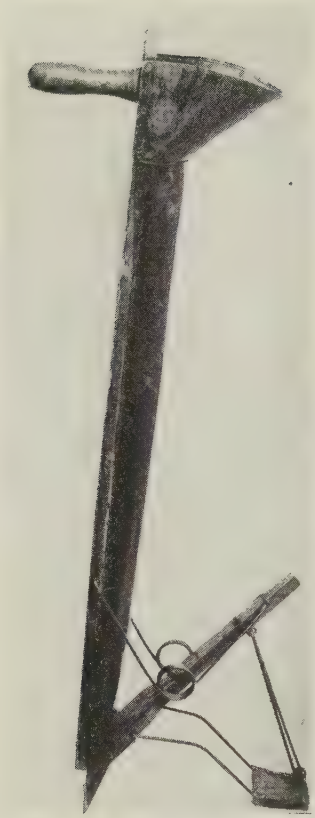


FIGURE 28. - *A hand planter for experimental plots.*

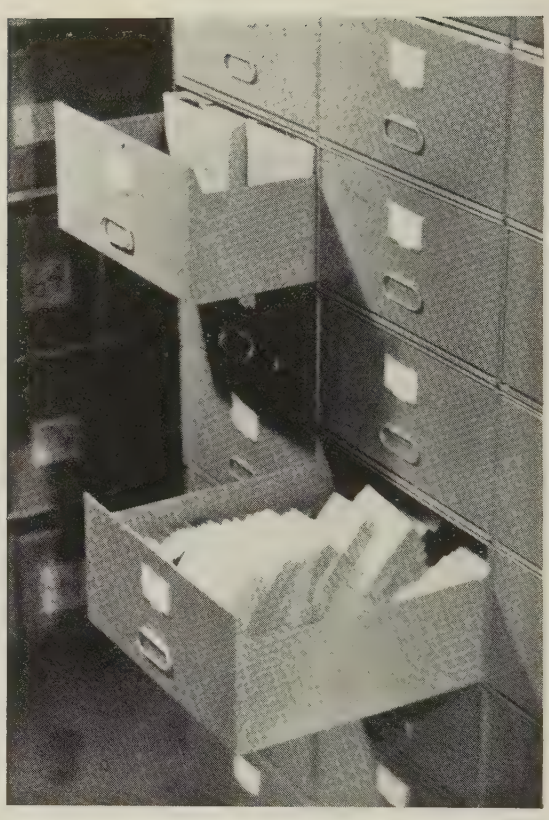


FIGURE 29. - *Seed storage should be arranged in convenient containers in a cool, dry, insect-free place.*

2½ inches by 4 inches in size are satisfactory for the seed of each inbred line. These packets can be arranged in boxes and numbered in the order of planting. Size of plot of each inbred line may vary from a hill of three or four plants to a row of 15 to 30 plants.

The land should be prepared in the usual way for maize. The field should be marked in advance in each direction with some type of marker. Seed in the breeding or testing plots is usually planted with a hand planter equipped with a seed tube and a funnel at the top into which the seed can be dropped (Figure 28). A carpenter's apron with rounded corners in the pockets is useful for carrying seed and empty packets. Fewer mistakes will be made if never more than one packet is picked up at a time during the planting operation.

All of the rows should be well marked, before the pollinating season begins, with substantial labels that will last until the crop is harvested. Labeling can be done with wooden sticks driven into the ground or with

durable tags or strips of paper. Labeling the rows or plots at each end saves time during the pollinating, notetaking, and harvesting seasons. Durable paper strips may be fastened around the plants with a hand-stapler. Tags may be fastened to the plants with a durable rust-proof wire or strong string.

Satisfactory techniques are available for making disease inoculations and insect infestations in programs for breeding for resistance. These techniques will be discussed more fully in later chapters.

Ruled notebooks with columns about 4 inches by 8 inches in size are satisfactory for records on inbred lines. A simple system of keeping pedigree records is indispensable in any breeding program. A common method is to assign ear numbers which may be preceded by a prefix indicating the source material, state, or country. Letters for this purpose have been assigned and are being used by maize breeders in the Corn Belt of the United States. Automobile license letters have been suggested for use in Europe in designating the country originating the inbred lines.

Notes should be taken at appropriate times on all characteristics in which the worker is interested. These notes on each character usually can be recorded in five numerical grades. Grade 3 indicates that the inbred line is about average for the characteristic. Grade 2 may be assigned an inbred line that is better than average, and Grade 4 can be given to one that is poorer than average. Grade 1 may be given to unusually desirable inbreds, and Grade 5 to unusually poor ones. This system of grades is convenient, classifies the material into convenient groups and is adapted for obtaining averages from different plots, years, etc.

Harvesting should be completed before frost damage has occurred. Undesirable ears should be discarded and desirable ones selected, tagged, dried, shelled, and stored. Care must be taken to prevent mixtures or damage to the seed. Storage should be arranged in convenient containers in a cool, dry, insect-free place. A desirable type of storage is shown in Figure 29.

Characteristics of Some Available Inbred Lines

Maize breeders need agronomic and other information on available inbred lines. Most of the inbred lines developed by maize breeders in agricultural experiment stations in the United States have been described in Corn Conference reports of the north central, northeastern, and southern regions of the United States (Jenkins, *et al.*, 1937-1954).

A group of 145 standard American inbred lines were compared in many locations in 1948 by members of the North Central Corn Improvement Conference of the United States. These lines involved most of the open-pedigree hybrids developed by the Corn Belt agricultural ex-

periment stations and in use prior to 1948. A second uniform test of inbred lines in 1949 included 89 entries, 49 of which were new. Data from both years were summarized by Brunson, Ullstrup and Dicke (1948, 1949).

Some of the agronomic data obtained in the uniform inbred tests of the North Central Corn Improvement Conference are summarized in Tables I and II in the Appendix. A similar summary of disease and insect ratings is given in Tables III and IV in the Appendix. The chemical composition of 145 inbred lines is shown in Table V in the Appendix. The reports presented original data from the cooperating stations and also averages of some of the data. Most of the data in Tables I to IV inclusive in the Appendix, are averages of the results obtained at the several stations. Since all entries were not grown at all stations, averages are not always comparable between the different maturity groups, but should be comparable among lines within a group.

Additional information on inbred lines is available in mimeographed and printed publications from maize breeders of various agricultural experiment stations in the United States and other countries. Reports of FAO Hybrid Maize Meetings are especially useful.

8. BREEDING SYSTEMS

The development of superior inbred lines is not a very efficient procedure. Maize hybrids in commercial production throughout the world involve relatively few inbred lines. These few elite inbreds are the survivors of literally millions of pollinations. In the Corn Belt of the United States, it is also becoming more and more difficult to develop any inbred lines definitely superior in all characteristics to the better ones now available.

Lindstrom (1939) commented on the uniformly poor phenotypic character of the inbred lines obtained by continuous self-fertilization with selection within and between progenies of selfed ears. He estimated that at least 100,000 inbred lines had been isolated in the previous five years. Each of these inbred lines was seriously defective in one or more characters in addition to its poor yielding ability. Genetically, he believed that at least four factors were responsible for failure to obtain extremely vigorous inbred lines:

1. a very large number of genes;
2. the blinding effects of environment in the selection program;
3. a complex and intricate interaction of genes;
4. a failure in the method of isolating such lines.

Most of the inbred lines now in use were developed by selection within and among self-fertilized lines. Single-hill selection, cumulative selection, and gamete selection have been suggested as efficient aids in this procedure. Recurrent selection and reciprocal recurrent selection may provide source material from which superior lines can be developed. Doubling of monoploids (haploids) is being used for producing homozygous diploids.

Selection in large populations, backcrossing, and convergent improvement may be utilized for the improvement of established inbred lines. Each of these breeding procedures has certain advantages and disadvantages. Variations and combinations of some of these methods are often desirable.

Plant breeders have been able to obtain inbred lines in the second and later cycles that were more vigorous than the original lines. Theoretically, it might be possible to obtain superior-performing hybrids by using such second cycle inbred lines. Unless extreme care is taken, however, the relationship gradually accumulating in the source material may in time result in lessened heterosis and lowered yield of hybrids. In an effort to eliminate this possibility, many of the inbred lines used in the Corn Belt of the United States have been assigned to two separate groups A and B by Stringfield, Brunson and Tatum (1953). The lines within each group may be crossed together as source material for the development of new inbred lines. Crosses for this purpose should not be made between lines of group A with lines from group B. This procedure ensures having unrelated inbreds to use in double cross hybrid development.

Standard Method

The standard method of developing inbred lines usually involves selecting plants and ears during the inbreeding period on the basis of the physical appearance of a row of plants grown from the same ear. This procedure has been an effective method of producing inbreds. In fact, most present-day hybrids involve inbred lines developed by this standard method.

The following example is fairly typical of the procedure followed:

First year. Self-pollinate several hundred or more selected plants of desirable open-pollinated varieties or hybrid material. Discard ears and plants of poor appearance.

Second year. Grow 25 to 30 plants in a row from each self-pollinated ear. Self-pollinate five to eight desirable plants in each row. Practice selection within and between progenies. Save the better three to five ears from the better plants in each selected row.

Third year. Plant three to five ears of each selected family ear-to-row. Self-pollinate desirable plants. Select the best row of each family on the basis of appearance. Discard the other rows. Save the three to five better ears from desirable plants of the selected row. This procedure is repeated until each inbred line is relatively homozygous.

Evaluation of the inbred lines in test crosses can be started in the early generations of inbreeding or delayed until the families are relatively homozygous. Progenies of 25 to 30 plants give opportunity for selecting *within* and *between* sub-families. However, only a limited amount of material can be handled, and a low percentage of desirable lines is obtained.

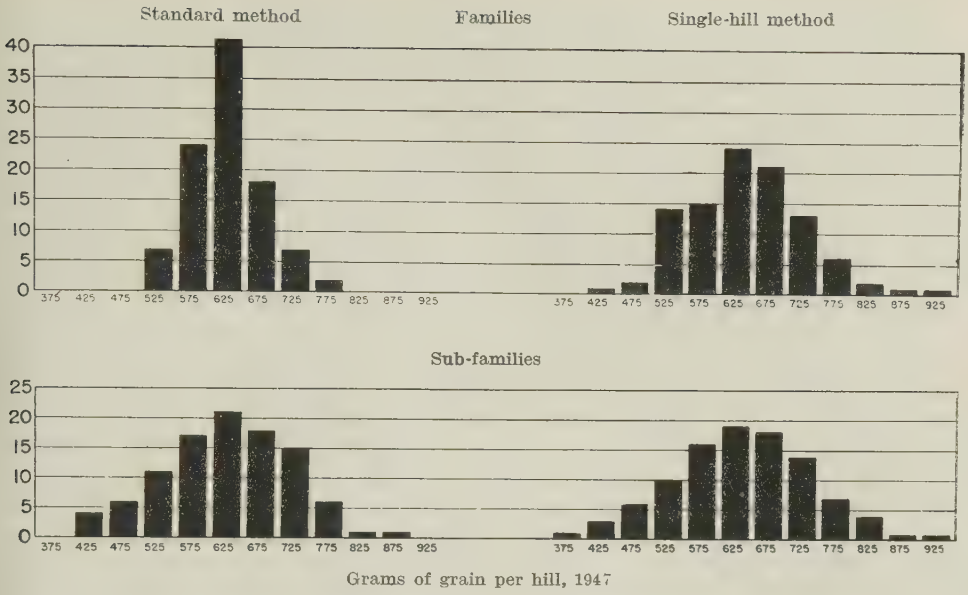


FIGURE 30. - *Grams of grain per hill from standard and ear-to-hill methods of developing inbred lines.*

Single-Hill Method

Single-hill selection is similar to the standard method, except that only one hill of three or four plants is grown from each ear. The method was suggested by Jones and Singleton (1934). Singleton and Nelson (1945) elaborated slightly on the procedure. The method was used by Woodworth at the Illinois Station to develop inbred line R30. However, few maize breeders have used the method, and the most direct and extensive evidence of its possible value was obtained by Jugenheimer (1948a, 1949a, 1949c, 1954b, and unpublished) at the Illinois Station.

Jugenheimer made direct comparisons of single-hill versus standard method of developing maize inbred lines. Three hundred selected ears were planted in single hills. In order to simulate standard procedure, 60 of these ears, taken at random, were planted in five-hill plots. Thus each method of developing inbred lines had the same number of plants. Two plants in all hills of both breeding systems were self-pollinated, and also crossed with an adjacent single cross tester to obtain information on specific combining ability.

The two methods of selection in 1947 are compared in Figure 30. Three-way crosses involving the inbred lines developed by the standard procedure ranged from 425 to 875 grams per hill, or over 10 classes. Maize

breeders are primarily interested only in elite lines. Two percent of the lines yielded at least 825 grams per hill. Yields from the single-hill material ranged from 375 to 925 or over 12 classes. Thus 6 percent or three times as many elite lines were obtained from the single-hill method as from the standard procedure. All of these elite lines from the single-hill material were unrelated and could be utilized in commercial hybrids whereas many of the elite inbreds from the standard procedure were related sub-families, and could not be used in the same hybrids.

The average performance of the families developed by the standard procedure is shown in the upper left hand corner of the chart. The mode is still 625 grams but the range is only half that of the sub-families. Most maize breeders have so many families to test that they composite the sub-families and conduct one test for the family. Ordinary procedure of testing a composite of all sub-families would have missed detection of the elite inbred lines. The results of compositing the two sub-families of the ear-to-hill material are shown in the upper right hand corner. Single-hill procedure resulted in detecting four percent of elite lines not detected by the standard procedure. Similar results were obtained in 1948 and 1949.

The importance of testing sub-strains of S_1 generation inbred lines in hybrid combinations in early years of development was studied by the author in 1936 and 1937. A composite of each family and five sub-strains of each of seven families were crossed with WF9 $\times$ Hy. Each family was assigned a number from 2 to 8 inclusive.

The distribution of the performance of the three-way crosses is shown in Figure 31. The tester yielded 19 pounds of grain per plot. Average yields of the families ranged from 16 to 18 pounds per plot. None of these crosses were as high-yielding as the tester. Testing of the sub-families, however, resulted in detecting six unrelated inbred lines as good as or better than the tester. Sub-strains of family 8 ranged from 14 to 20 pounds per plot. All sub-strains of family 7 were poor in yielding ability, while all sub-strains of family 4 were quite good in this trait.

Percentage of erect plants at harvest of the sub-families in three-way crosses ranged from 20 to 90. Families 2 and 4 averaged 70 percent erect, while all sub-strains of family 8 averaged only 48 percent erect. Sub-strains of family 7 ranged from 30 to 90 percent erect (Figure 31).

Performance of test crosses indicated that the single-hill method of developing inbred lines was more efficient per pollination than the standard method as commonly conducted by maize breeders. Most workers conduct a test on a new inbred on composited ears of the family. Such tests usually miss detecting the best sub-line in the segregating population. Efficiency of the standard method was materially increased by evaluating individual plants of sub-families in test crosses in the early years of inbreeding. Many of the elite inbred lines would have been discarded if ears of

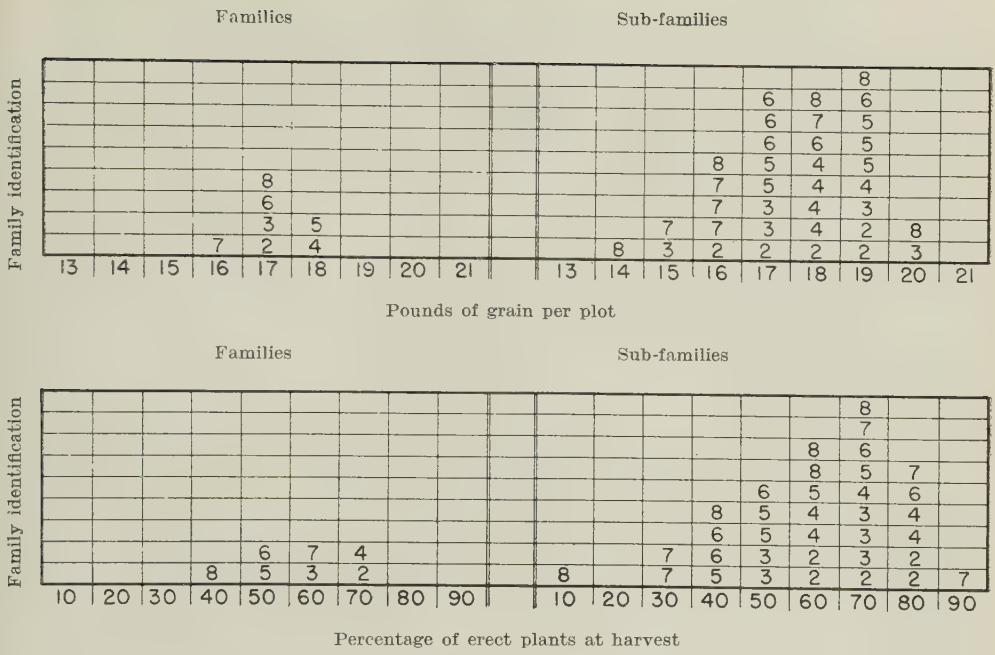


FIGURE 31. - *Distribution of performance of inbred families and sub-families in three-way crosses.*

sub-families had been composited and only one test conducted on the family. Testing may be delayed or started in the early generations of inbreeding. Single-hill selection has proved to be a desirable procedure at the Illinois Station for maize, small grains, and soybeans.

Single-hill procedure at the Illinois Station is as follows:

First year. Self-pollinate a large number of selected plants of desirable open-pollinated varieties or hybrid material. Save self-pollinated ears from desirable plants. Six seeds are taken from selected ears and put in separate packets for planting.

Second year. Seed from each packet is dropped by hand planters in separate hills. Plants in individual hills are thinned to the desired stand. The best plant in each hill is self-pollinated, and may be crossed with an adjacent tester for preliminary evaluation the following year. A synthetic or widely-used open-pollinated variety is used as the tester when information is desired on "general combining ability". A single cross, commonly used as seed parent in hybrid seed production, is used to obtain information on "specific combining ability". Families with poor phenotypes are discarded. The self-pollinated ear on the best plant per hill is saved at harvest time to continue each line.

Third year. Selected selfed ears from the second year are planted ear-to-hill. One selected plant per hill is self-pollinated and also crossed with

the adjacent tester. The large number of test crosses from the second year are compared in replicated, single-hill or larger plots. Their performance may be compared with one another and with the tester. Efficient use of single-hill plots for testing requires uniform soil and practically perfect stands. Inbred lines involved in poor-performing test crosses are discarded.

Fourth year. Inbred lines whose performances in test crosses appear promising are planted ear-to-hill. One selected plant per hill is self-pollinated and crossed with adjacent plants of the tester. Test crosses made in the third year are again compared in performance trials in replicated, single-hill or larger plots. The above procedure is continued for three or more generations. Since each ear represents an unrelated inbred line, individual labeling of lines is not necessary until testing is started.

Single-hill development of inbred lines can be utilized efficiently in recurrent, reciprocal recurrent, gamete, cumulative, and other types of selection. This procedure limits selection primarily to differences between families. However, experience has shown that differences *between* families are much greater than those *within* families. The method enables sampling many families with little effort since it permits growing at least 10 to 20 times as many families as standard selection. Obviously, more plants of each line may be grown whenever deemed desirable. The method is a very effective one if it can be used with an adequate testing program.

Cumulative Selection

Cumulative selection was discussed by Richey (1945). The method involves the development of inbred lines by standard procedures, and a repetition of the cycle by inbreeding plants of crosses among the better first cycle lines. The procedure was suggested as an efficient method of obtaining a higher percentage of desirable lines for a given amount of effort.

Richey outlined four phases of the program:

1. An initial period of visual selection for individual plants in desirable progenies. Selection during the first cycle eliminates gross recessives and tends to fix dominants. Each family may contain several subfamilies. Richey suggested that testing be delayed until the fourth or fifth generation of inbreeding.

2. Testing for combining value. Testers could be open-pollinated varieties or single crosses, depending on whether one was primarily interested in general or specific combining value. A preliminary test could be conducted after three generations and would be followed by another after five generations. The families chosen after the first test could be immediately utilized in various combinations.

3. Crossing among the high combining families. The inbred lines chosen on the basis of their performance in tester crosses could be combined for another cycle of inbreeding.
4. A second cycle of selection would be based on selfed progeny performance. Since selection during the first cycle tends to eliminate gross recessives and fix the dominants, Richey believed that selection during the second cycle could be based on selfed progeny performance.

Hayes and Johnson (1939) found that the total yield of second cycle inbreds from two nursery rows provided a reasonable criterion of their combining value. Encouraging results were obtained from the second cycle of selection by the Minnesota workers. They found that inbred lines from crosses of two high combining parents tend to be high combining. The new inbred lines, however, still need to be evaluated in test crosses.

Cumulative selection procedure might be outlined as follows:

First year. Self-pollinate desirable plants in an open-pollinated variety or hybrid material. The better ears from the selected plants of each row should be saved.

Second year. Ears are saved from the better plants in the best families and progenies are grown from them the next year. Selected plants should be self-pollinated.

Third year. Plant selected ears from the better progenies grown the previous year. Self-pollinate selected plants.

Fourth year. Plant selected ears of the better progenies from the third year. Self-pollinate the better plants. These inbreds also should be crossed with a suitable tester.

Fifth year. Self-pollinate selected plants of the better families. Conduct performance trials on the test crosses made in the previous year.

Sixth year. Self-pollinate selected plants of the better families. Continue to evaluate the inbred lines in various combinations. Cross the better lines as source material for another cycle of inbreds.

Seventh year. Self-pollinate in new source material and repeat the procedure.

Cumulative selection may not be as efficient as recurrent selection because of the longer period required to complete each cycle. The relationship accumulating in the material may in time result in lessened heterosis and lowered yields of hybrids.

Gamete Selection

Gamete selection was suggested by Stadler (1944, 1945) as an efficient procedure for developing inbred lines. The method is especially useful for producing an inbred line to replace one involved in a double-cross hybrid. Stadler suggested that the procedure enables the breeder to use the gamete as the unit of selection.

Hayes, Rinke, and Tsiang (1946) suggested that gamete selection could be used to select gametes from such sources as synthetic varieties, hybrids, and inbred lines. They, and Pinnell, Rinke and Hayes (1952) discussed gamete selection in its relation to the improvement of specific double crosses.

An illustration of the gamete selection technique involves improving WF9 in U.S. 13, which is a hybrid with the following pedigree: (WF9 × 38-11) × (Hy × L317).

First year. Cross selected plants of an open-pollinated variety or hybrid material with WF9.

Second year. Self selected F_1 plants. Cross these same plants with Hy × L317. Cross the original WF9 with Hy×L317 to use as a standard check.

Third year. Test the crosses produced in the second year. Select the better performing lines for continued inbreeding. Self-pollinate selected plants of the S_2 inbreds or store them pending evaluation of the test crosses.

Fourth year. Self-pollinate selected lines. Retest the crosses produced in the second or third year.

Fifth year. Continue self-pollination of selected lines until homozygous.

Sixth year. Substitute new $WF9^1$ in original hybrid and use commercially as ($WF9^1$×38-11) × (Hy×L317).

Gamete selection is another application of the principle of early testing. It would appear to be especially useful in sampling open-pollinated varieties in order to obtain a broader genetic base for further recombination and selection. The method should increase the frequency of the exceptional genotypes from the varietal population with greatly increased frequency of the most exceptional types. Gamete selection should also give improved control of other important characters in addition to yield. The procedure increases the possibilities of further improvement by selection in S_1.

General combining ability is not usually determined in gamete selection. The inbred line derived in the example mentioned above is restricted to hybrids not involving WF9. A very accurate performance test is required to detect significant differences, since the gametic genotypes compared represent only half of the genotype of the plants which are tested.

Recurrent Selection

Jenkins (1940) studied the segregation of genes affecting yield of grain in maize. His results emphasize the greater chances of obtaining elite inbred lines through selection *among* large numbers of lines rather

than *within* lines. He also found that the yield prepotency of lines in hybrids, as measured by their top crosses, may be determined very early in the inbreeding period.

Based on the results of his research, Jenkins (1940) suggested a type of recurrent selection for developing synthetic varieties from short-time inbred lines. The essential steps in the procedure are:

1. the isolation of one-generation selfed lines;
2. testing of these lines in top crosses for yield and other characters to determine their relative endowments with respect to genes affecting these characters;
3. intercrossing of the better-endowed selfed lines to produce a synthetic variety.

Four different types of recurrent selection have been discussed by Sprague (1955). These include:

1. recurrent selection;
2. recurrent selection for general combining ability;
3. recurrent selection for specific combining ability;
4. reciprocal recurrent selection.

Recurrent selection for specific combining ability was suggested by Hull (1945). This breeding method appears to be especially well adapted for developing a single cross to substitute for another in a double-cross hybrid. The plan involves several steps:

1. self-pollinating 100 or more plants in a crossbred lot and crossing these onto a specific tester;
2. comparing the test crosses;
3. intercrossing the 10 or more better S_1 inbreds;
4. repeating the cycle and using the intercrossed seed from the previous cycle as germ-plasm material;
5. utilizing the two better inbred lines in a single cross which is then combined with the tester cross to make a new double-cross hybrid for commercial use.

The following plan is typical of recurrent selection for specific combining ability:

First year. Self-pollinate a large number of plants in the source material. Cross each self-pollinated plant with a desirable single cross tester. Discard extremely undesirable plants.

Second year. Self-pollinate the new S_1 inbreds and again cross them with the tester single cross. Compare the three-way crosses produced in the first year in replicated plots.

Third year. Make all possible single crosses among the 15 to 20 better families as determined by the previous year's test. These single crosses

are used as a source of another cycle of inbred lines. The two or more better inbred lines are combined into single crosses which eventually are used in double-cross hybrids. Again compare the three-way crosses in replicated plots.

Fourth year. Combine selected single crosses with tester to make new double crosses. Start a new cycle of inbreeding. The cycles of recurrent selection may be continued as long as improvement is obtained.

Hull believes that by using the 10 better inbred lines developed by self-pollinating 100 tested plants, four cycles should have an efficiency equal to testing 12,000 plants from the original population. This breeding scheme has not been thoroughly tested experimentally, but it is of considerable theoretical interest and appears to have practical possibilities. The method provides for recurrent selection for specific combining ability. General combining ability of the inbred lines may be evaluated also if deemed desirable. Phases of recurrent selection have been discussed by Hull (1945, 1952), Lonnquist (1949, 1951), Sprague and Brimhall (1950), Sprague, Miller and Brimhall (1952), Jenkins, Robert and Findley (1954), and Hayes, Immer and Smith (1955).

Reciprocal Recurrent Selection

Reciprocal recurrent selection was suggested by Comstock, Robinson and Harvey (1949). This procedure is a modification of recurrent selection but utilizes foundation material from two sources, A and B. Source material might involve two or more open-pollinated varieties or synthetics. The foundation material should be as genetically divergent as possible but should combine well together since the hybrids to be developed will involve crossing inbred lines descended from both sources.

Plants from source A are self-pollinated, and at the same time, outcrossed to a sample of plants from source B. Self-pollinated plants from source B are tested against source A plants in the same way. Selection is based on performance trials of top-cross progenies. Selected inbred plants are intercrossed the third year using their selfed seed produced the first year. The cycle is reinitiated the fourth year.

Detailed procedure in utilizing reciprocal recurrent selection might be as follows:

First year. Self-pollinate 200 selected plants from source A and a like number from source B. Cross each of the self-pollinated plants from source A with four or five plants taken at random from source B. Cross each of the self-pollinated plants from source B with four or five plants from source A. Testing these crosses the second year will provide information on general combining ability of the inbreds and desirable source material for another cycle of inbreeding.

Second year. Compare the test crosses made in the first year in performance trials. Test seed from the several plants involving each new inbred line should be composited for testing. Thus there would be 200 topcross entries in each of two trials for general combining ability. The S_1 inbreds may be self-pollinated again, or they may be laid aside while the test crosses are being evaluated.

Third year. Seed of inbred lines whose crosses were superior in the previous year's field trials are planted ear-to-row or ear-to-hill. The better performing inbreds from source A, based on their performance in top crosses, would be combined in all possible single-cross combinations and used as source material for another cycle of inbreeding. The same procedure would be followed with inbreds from source B.

Fourth to sixth years. The procedure as followed during the first three years would be repeated, using group A and B seed produced in the third year.

The inbred lines developed during each cycle of reciprocal recurrent selection may be maintained and tested in double cross hybrids for commercial use. Information on specific combining ability may be obtained by crossing each of the self-pollinated plants from source A onto plants of a desirable, unrelated single-cross seed parent. Similarly self-pollinated plants from source B are crossed with another unrelated single cross. The elite inbreds, based on their performance in three-way crosses, should be combined into single crosses. These single crosses, in turn, should be crossed with the respective single cross testers into double crosses. Other double cross hybrids could be produced by combining single crosses involving desirable inbreds from source A with single crosses involving selected inbreds from source B.

Comstock *et al* (1949) point out that, by testing source A plants in crosses with source B plants, selection pressure for the specific genes which contribute most to the cross of material from the two sources is insured. Sufficient numbers of plants should be selected in each generation to hold the inbreeding within the two source-material groups at a low level in order to prevent loss of the within-group variability on which selection operates. Plants selected in any generation should not all trace to one or two crosses made in an earlier cycle of the program. Consequently, controlled pollination must be accompanied by a recording of the pedigree.

Reciprocal recurrent selection may be more effective than either recurrent selection for specific combining ability or selection based on general combining ability with a common tester series irrespective of overdominance, dominance or partial dominance. This is a new and very promising breeding method but little actual data are available in the literature.

Doubling of Monoploids

Isolation of monoploid maize plants by genetic screening methods was suggested by Randolph (1932, 1940). Improvements in the procedure were suggested by Chase (1949, 1951, 1952) and Alexander (1952, 1953).

A monoploid (also termed haploid) is an individual possessing half the normal chromosomal complement. It is a sporophyte possessing a single genome per cell. Haploids of maize carry only one set of chromosomes per cell and are normally designated as monoploids for this reason.

Many maize breeders are interested in producing inbred lines by doubling monoploid plants. Chase (1952) outlined the following procedure. The source material may be a selected hybrid or an open-pollinated variety.

Plants are pollinated with a genetic marker stock such as purple aleurone and purple plant color. The normal kernel progeny of such a cross will develop purple aleurone, and the normal, diploid plant progeny will develop purple color in various plant parts. The aleurone marker is used to detect pollen contaminations. Yellow kernels are discarded as probable products of self- or cross-pollinations. Plants developed from purple kernels, but which lack purple plant color, are the putative monoploids. A further check on the actual monoploids in this relatively small group is by chromosome counts and by general appearance of the mature plants.

The monoploid plants are usually weak, small, and highly sterile. Their frequency is highly variable, ranging from 1:1500 to about 1:27. The purple color of the marked seedlings also appears in the seedling roots.

Consequently, the genetic classification for plant color may be carried out on germinator trays during the first five to ten days. Non-purple seedlings from purple kernels are transplanted to the field or greenhouse and are grown to maturity. All plants producing pollen are self-pollinated.

Success in reproduction of the self-pollinated plants may be increased by colchicine treatment of the monoploids. The procedure involves the injection of a weak colchicine solution into the scutellar node of the putative monoploids as soon as they are recognized. This treatment usually results in the production of selfed progeny of about one monoploid in five.

Genetic methods may be used to increase the reproductive success of monoploids. Chase found that monoploid-derived stocks are particularly rich sources of sub-fertile monoploids.

The following monoploid procedure is being used by Alexander at the Illinois station:

First year. Production of source material. The source material serving as seed parent is crossed with a brown tester to produce the screening hybrid as follows:

Seed Parent		*Brown Tester*
$\frac{A_1\ A_2\ A_3\ b\ pl\ c\ r^r\ Pr}{A_1\ A_3\ A_3\ b\ pl\ c\ r^r\ Pr}$	$\times$	$\frac{a_1\ A_2\ A_3\ B\ Pl\ C\ R^g\ Pr}{a_1\ A_2\ A_3\ B\ Pl\ C\ R^g\ Pr}$

Second year. Select monoploid plants. Germinate the purple kernels from the screening hybrid. The temperature of the germinating chamber should not exceed 68° F. to 70° F. High humidity and complete darkness should also be maintained. After four or five days the white-rooted seedlings are removed, and the growing point and scutellar node are treated with a hypodermic injection of 0.05 percent colchicine and 10 percent glycerine in water. The treated plants are potted and observed for physical characteristics. The plants are transplanted in the field after they have recovered from the initial shock of treatment. The plants are examined at two-hour intervals during anthesis. Many plants will extrude only one or two anthers; others will have large chimeras of diploid tissue in the tassel. Plants with pollen and silks should be self-pollinated. The seed should be harvested as soon as practicable. Insect and disease damage on individual kernels on successfully developed plants is common.

Third year. The selfed seed produced on the monoploid seed parent in the second year is planted in the third year. These plants are self-pollinated and crossed with a tester for an evaluation of their combining ability. The doubled monoploid plants should be completely homozygous.

Monoploids appear to be valuable tools for physiological research and cytogenetic studies. Since doubled monoploids should provide a completely homozygous population, variation in plants must be due to mutations or environmental effects. They should be suitable material for radiation studies. Chase points out that monoploids can be used in

"the cytological field for studies of the meiotic distributions of unpaired chromosomes, *non-homologous* synaptic relations of the chromosomes and mechanics of chromosome doubling; in the genetic field for direct observation of mutational effects, measurement of mutation rates, studies of cytoplasmic effects, and biochemical investigations; in the agronomic field for the production of diploid, homozygous stocks directly from the monoploids."

The advisability of using this system in a breeding program depends upon two main problems:

1. relative cost or efficiency of monoploid doubling compared to usual self-pollination;
2. phenotypic and genotypic characteristics of the inbred lines compared to lines derived in the usual manner.

The rates of occurrence and fertility of monoploids are very low for some stocks. Open-pollinated varieties appear to offer more difficulty than hybrid material. The monoploid method is similar to gamete selection and late testing. Successful doubling results in fixing a particular gamete which can be reproduced in the future. The method resembles late testing in that the derived line is not tested in combination with other inbreds until it is homozygous.

Ford (1954) studied the frequency of occurrence of abnormal individuals among the progeny of monoploids as indicated by pollen abortion and meiotic irregularities. She found that autodiploid lines and other monoploid derivatives are no more likely to be meiotically aberrant than lines developed by inbreeding. The relative effects of natural selection upon the monoploid sporophyte has not been compared with selection practiced by a breeder upon segregating populations of normally selfed material. Monoploids, however, should carry well-balanced genetic systems, since passage through the sporophyte stage as a monoploid involves drastic selection against lethal and sublethal genes.

Alexander (1952) pointed out that lines produced by doubling monoploids are homozygous at all loci; that the process greatly reduces the time needed to produce inbreds; that selection for highly desirable genetic combinations can be made more efficiently on the gametic basis than on the zygotic basis; and that individuals possessing deleterious genes are eliminated, since the monoploid sporophyte is subjected to intense natural selection. However, the technique for isolating monoploids is tedious and complicated; not more than 20 to 30 percent of the treated monoploid plants produce viable pollen; immediate fixation of the genotype eliminates opportunity of selection: and selection on the basis of the gamete rather than the zygote may not be of great importance in producing superior lines. The need for, and possibility of, developing homozygous inbred lines for special purposes makes the method a valuable one.

Oenothera Method

The " Oenothera " or multiple translocation method of developing inbred lines was suggested by Burnham (1946). This method suggests utilizing translocations in such a way that the F_1 of crosses with normal stocks will have a ring at meiosis containing the entire diploid number of chromosomes. Such a plant should produce two kinds of functional spores corresponding to the two parental gametic combinations of chromosomes. The other combinations abort in maize. If no lethals are present, the offspring from selfing such a plant should consist of heterozygotes with the chromosome ring, recognizable by high-pollen abortion. Two types of normals, each homozygous for one of the two parental game-

tic combinations would also be present. These two types of normals would have normal pollen and normal number of chromosome pairs, and could be distinguished by crossing them with the standard normal stocks. The normal type, not carrying the translocations, would constitute the homozygous inbred.

Chances of isolating superior inbreds should be the same as the frequency with which superior gametes occur in the heterozygous population.

The steps in utilizing the multiple translocation method are outlined below:

First year. Cross selected plants with the multiple translocation stock. Source material may be open-pollinated varieties or hybrids. Differences in each of the F_1 plants would be due to a different gamete.

Second year. Self-pollinate F_1 plants which show a high degree of sterility.

Third year. Grow F_2 progeny of the F_1 plants that were self-pollinated in the second year. Self-pollinate desirable plants which have normal pollen, and cross these plants with the normal tester stock.

Fourth year. Grow test crosses in performance trials, and examine the pollen of the plants. Save inbred lines whose test cross plants had normal pollen. Plants having normal pollen would indicate the absence of translocations and would be the desired homozygous inbred. Test crosses in which all of the plants were partially sterile indicate that the normal parent being tested was homozygous for translocations and was not the desired line. Each F_1 plant in the second year would be a starting point of a different homozygous inbred. These lines could be evaluated in the same manner as inbred lines obtained by continued inbreeding. Selections and crosses for the performance trials could be made immediately if the normal stocks obtained in the third year were grown in the field with the test crosses.

Burnham (1946) suggested that the above procedure might be improved in several ways. Some of the test crossing of normals could be eliminated if recessive genetic markers were incorporated in the multiple translocation stock. These markers would aid in recognizing and discarding most of the F_2 plants that were homozygous for the translocations. Plants homozygous or heterozygous for the translocations might be recognizable if dominant markers were incorporated. In this case, only the normal alleles would need to be checked for pollen sterility. Remaining normal plants should be test crossed.

The " Oenothera " method of developing inbred lines was suggested on a theoretical basis, and has not been tested. Richey (1947) questioned whether the immediately achieved homozygosis might be disadvantageous because of the fixing of deleterious recessives before they could be eliminated by selection. He pointed out that Macaulay (1928) found that the selfing might proceed too rapidly toward homozygosis for best results.

Selection in Large Populations

No inbred lines of maize available at the present time approach the parent varieties in vigor or yield. These inbred lines also have faults which they contribute to their hybrids. Improvement of established inbred lines might be done by:

1. selection in large populations;
2. backcrossing;
3. convergent improvement.

Selection in large populations is a simple, rapid, and effective method of improving inbred lines in populations where variation occurs for the desired characters. The procedure utilizes the selection of improved types which often occur in a large population of plants. Variation is provided by hybridization, delayed segregation, and mutation. The criterion for selection may be visual judgment or progeny testing. The procedure, however, usually requires large numbers of plants, and often there is not enough variation among the plants of an inbred line to find the improved types. Hy2 and 5120^{B} are examples of Illinois inbred lines which have been improved by selection in large population.

Backcrossing

The cross of a hybrid to one of the parents is a back cross. The backcross method of breeding is especially useful in transferring one or two simply inherited characters of the nonrecurrent parent to the recurrent parent. The recurrent parent usually is an inbred line which is satisfactory in most respects, but is faulty in one or a few other characters. Thus the recurrent parent is the inbred line needing the improvement, and the nonrecurrent parent contributes the desired characters. Selfing is practiced to fix the dominant genotype. If the desired character is recessive, alternate backcrossing and selfing allows expression of the character before the next back cross is made.

Harlan and Pope (1922) pointed out the use and value of backcrossing in cereal breeding. The method has been successfully used by many maize breeders but has been neglected by many others. Excellent recent reviews of the backcross method of plant improvement have been made by Harrington (1952), Stringfield (1952), and Hayes, Immer and Smith (1955).

Backcrossing is a much more potent plant improvement tool than "selection in large populations". It introduces improved characters into the inbred line and provides a systematic method of improving the

line step by step. The method is somewhat complicated, requires a careful choice of the nonrecurrent parent, needs a population of sufficient size to provide for segregation of the desired type, and linkage may hinder success of the method.

Stringfield (1952) pointed out that:

> " Backcrossing provides a restricted genic segregation, restricted in that:
>
> 1. the genes in the backcrossed progeny are predominantly from the recurrent parent;
> 2. those genes contributed only by the recurrent parent become fixed as homozygous alleles (identical pairs), at a rate of 50 percent, more or less, with each successive backcross;
> 3. those genes contributed only by the nonrecurrent parent are never fixed as homozygous alleles, and are eliminated at a rate of about 50 percent, more or less, with each successive back cross."

Backcrossing permits segregation of those genes which the research worker wishes to have transferred but provides genetic stability for genes he wishes to remain unchanged. Obviously, the character to be transferred must be identifiable with reasonable clarity.

The formula $\left(\frac{2^r - 1}{2^r}\right)^n$ gives the percentages of plants homozygous for the n factors entering the cross only from the recurring homozygous parent in each of r successive generations [Richey (1927), Hayes, Immer and Smith (1955)]. These percentages are shown in Table 8.

Backcrossing to the homozygous dominant requires fewer progeny to obtain one dominant homozygous individual than selecting in an F_2 population. Based on independent inheritance, these results are shown in Table 9 [Hayes, Immer, and Smith (1955)].

Important steps in a backcrossing program are reviewed by Stringfield (1952):

> " Suppose the line of demonstrated worth has a white endosperm, but a yellow endosperm is needed. The line is crossed with a stock having the desired endosperm color. Since yellow endosperm is dominant over white, the F_1 seed will all be yellow, but heterozygous. The first backcross seed will segregate into white and yellow endosperms. The ratio of yellow to white will depend upon the number of genes for yellow in the specific cross, and several grades of yellow probably will appear for selection. The process now becomes one of continuously selecting the best grades of yellow seed, planting them, and backcrossing to the white kerneled, recurrent parent.
>
> After four generations of backcrossing, the resultant stocks are sometimes presumed to deviate from the recurrent parent by only $^1/_{32}$ of their genes. That value cannot be depended upon. In the first place it is not known what proportion of genes were alike, or essentially alike, in both parents. Segregation in that group has little or no effect in modifying the recurrent parent. The remaining genes become heterozygous in the F_1 generation, and they are the only ones that are subject to manipulation. Among this group the contribution of the nonrecurrent parent is assumed to be reduced as an average value to about $^1/_{32}$ after four back crosses.

TABLE 8. — PERCENTAGES OF PLANTS HOMOZYGOUS FOR THE n FACTORS ENTERING A CROSS ONLY FROM THE HOMOZYGOUS RECURRENT PARENT TO WHICH THE CROSS AND THE RESULTING PROGENIES ARE MATED IN EACH OF r SUCCESSIVE GENERATIONS

Number of factor pairs,	Number of generations of back pollinating, r									
n	1	2	3	4	5	6	7	8	9	10
1	50	75	88	94	97	98	99	100	100	100
5	3	24	51	72	85	92	96	98	99	100
10	..	6	26	52	73	85	92	96	98	99
15	..	1	13	38	62	79	89	94	97	99
20	..	..	7	28	53	73	85	92	96	98
30	..	..	2	14	39	62	79	89	94	97
40	..	..	..	8	28	53	73	86	92	96
50	..	..	..	4	20	46	68	82	91	95
75	..	..	..	..	9	31	56	75	86	93
100	..	..	..	..	4	21	46	68	82	91

SOURCE: Hayes, Immer, and Smith, 1955.

TABLE 9. — PROGENY REQUIRED TO HAVE ONE DOMINANT HOMOZYGOUS INDIVIDUAL

Method	Number of factor pairs							
	1	2	3	4	5	6	7	8
F_1, selfed	4	16	64	256	1 024	4 096	16 384	65 536
F_1, backcrossed to homozygous dominant	2	4	8	16	32	64	128	256

SOURCE: Hayes, Immer and Smith, 1955.

But this fraction is increased because of selection for characters of the nonrecurrent parent, which is, in effect, selection for genes of the nonrecurrent parent. Furthermore, these genes are linked together in groups. When the plant breeder selects a character and the genes that generate it, he unwittingly selects many other linked genes. The fraction of $^1/_{32}$ then, may have little relation to reality.

But if the plant breeder is satisfied with the approach to the recurrent parent after four back crosses, he can begin selfing to fix the yellow endosperm character as a homozygous dominant. At least two and probably three generations will be required for that. The breeder has then completed one of the simplest procedures in transferring a character by backcrossing with selection. It might have been more complicated if certain genes which modify endosperm color had been involved. In any case, the operation has required at least seven generations.

If the task had been to transfer the recessive white instead of the dominant yellow, it would have been necessary to self after the first back cross to reveal the plants having the white character. Selfing and backcrossing can be done at the same time by using pollen from backcrossed plants for both operations."

Backcrossing does not always result in improving inbred lines. This fact is illustrated in the *Report of the Co-operative Uniform Comparisons of Corn Hybrids - 1945* compiled by Jenkins and Mayer (1945). One series of tests was designed to evaluate inbred line L317 and eleven " recovered " strains of it. L317 and the recoveries were crossed with each of four widely-used inbred lines, Hy, WF9, 38-11 and K4. The 11 recovered strains of L317 had been backcrossed one or two times and then selfed from four to ten times. The crosses were compared in 10 different states. The recoveries differed widely in grain yield, maturity, standability and in resistance to *Helminthosporium turcicum*. Oh41 averaged better than the original L317 in most respects, while C.I. 22 averaged poorer than L317.

Backcrossing was used by Woodworth and Jugenheimer (1949) to transfer high protein and high oil content to standard inbred lines. The procedure has been used by Jenkins and Robert (1952) to transfer resistance to *Helminthosporium turcicum* from resistant Southern lines to Corn Belt inbreds. Many other workers have found backcrossing to be a convenient, efficient method of improving inbred lines.

Convergent Improvement

Richey (1927) suggested convergent improvement as a method for increasing the productiveness of inbred lines without interfering with their behavior in hybrid combination and for obtaining information on the nature of hybrid vigor.

Convergent improvement utilizes double backcrossing in an effort to improve characters of the two parental inbreds of an otherwise desirable single cross. The F_1 is backcrossed to both parents through several generations. Two or three generations of backcrossing usually result in obtaining progeny resembling the recurrent parent in appearance. Selection attempts to obtain and retain plants with the desired traits from both parents. The desired genes then are fixed by several generations of self-fertilization. Testing the performance of the recovered lines in field trials is a necessary procedure.

It is relatively easy to improve an inbred line by backcrossing for characters lacking in one inbred but carried by the other parent. These improvements include vigor and resistance to lodging and diseases. Thus such recovered lines are more practical to use in a seed production program.

Some workers have obtained higher yields from F_1 crosses between inbred lines improved by convergent improvement than from the F_1 crosses between the original parents. Most workers, however, have obtained lower yields from the F_1 crosses involving convergent improved lines than from the F_1 crosses between the original lines. A standard backcrossing program appears to be superior to convergent improvement.

9. EVALUATING INBRED LINES

Most maize breeders have found a correlation between the characteristics of inbred lines and their progeny. Special methods of inbred evaluation include the use of inversions and multiple recessive genes. Final evaluation of inbred lines, however, can be determined best by hybrid performance.

Correlations among Characters of Inbred Lines

The 378 possible correlations involving 28 plant and ear characters of 145 widely used inbred lines of maize are shown in Table 10. The original data are given in Tables I, III and V in the Appendix. Many of the correlations were statistically significant and should have some predictive value in selection.

Correlations between Characters of Inbreds and Hybrids

Many investigators have reported on the relation between various plant and ear characters of inbred lines and that of their progeny. These workers reasoned that, if certain characters are associated with performance, desirable inbred lines may be obtained more quickly and efficiently by selecting for such characters.

Kiesselbach (1922) reported a relation between the yield of inbred parents and that of their hybrid offspring. Richey (1924) noted that certain strains were very prepotent for yield. Richey and Mayer (1925) found that some inbred lines were much superior to others in producing high yielding hybrid combinations. Kyle and Stoneberg (1925) reported a correlation between certain plant and ear characters and smut resistance and productivity. Hayes (1926) found that yield was very strongly correlated with those characters of inbred lines which are the expressions of vigor.

Nilsson-Leissner (1927) reported positive correlations between certain characters of inbred lines and the same characters in their single-cross

TABLE 10. — CORRELATIONS AMONG 28 CHARACTERISTICS OF 145 INBRED LINES

Code	Character	1	2	3	4	5	6	7
1	Days to half pollen		+.934**	+.928**	+.731**	+.820**	—.542**	+.115
2	Days to half silk	+.934**		+.896**	+.732**	+.805**	—.518**	+.101
3	Days to maturity	+.928**	+.896**		+.718**	+.812**	—.491**	+.104
4	Plant height, in.	+.731**	+.732**	+.718**		+.885**	—.344**	+.081
5	Ear height, in.	+.820**	+.805**	+.812**	+.885**		—.426**	+.215*
6	Root-lodged plants, %	—.542**	—.518**	—.491**	—.344**	—.426**		+.038
7	Stalk-lodged plant, %	+.115	+.101	+.104	+.081	+.215*	+.038	
8	Plot yield, lb.	+.025	+.023	+.077	+.215*	+.059	—.060	—.059
9	Ears per plant, no.	—.049	—.009	—.062	+.031	+.001	—.038	+.216*
10	Reaction to 2-4D, gr.	+.077	+.102	+.098	+.248**	+.204*	+.133	+.055
11	Mg. deficiency, gr.	—.166	—.153	—.186*	—.218*	—.216*	+.132	—.059
12	*H. turcicum*, gr.	—.542**	—.534**	—.559**	—.396**	—.537**	+.255**	—.162
13	*H. maydis*, gr.	—.056	—.042	—.066	—.011	—.041	—.040	—.086
14	Diplodia stalk rot, gr.	—.245**	—.222**	—.211*	—.152	—.139	+.260**	+.149
15	Gibberella stalk rot, gr.	—.412**	—.394**	—.439**	—.322**	—.389**	+.198*	—.022
16	Smutted plants, %	—.315**	—.294**	—.305**	—.244**	—.270**	+.339**	—.003
17	Kernel rot, gr.	+.015	+.030	+.036	+.133	+.066	—.112	—.094
18	Eur. borer oviposition, gr.	+.079	+.111	+.096	+.040	+.084	—.185*	+.160
19	Eur. borer leaf feeding, gr.	—.323**	—.339**	—.279**	—.122	—.153	+.151	+.022
20	Eur. borer plant injury, gr.	—.234**	—.274**	—.233**	—.256**	—.187*	+.154	+.090
21	Eur. plant tolerance, gr.	—.275**	—.305**	—.282**	—.294**	—.239**	+.217*	+.120
22	Corn ear worm, gr.	—.304**	—.265**	—.284**	—.160	—.234**	+.198*	—.028
23	Leaf aphids, index	+.509**	+.512**	+.573**	+.373**	+.452**	—.227*	+.070
24	Thrips, gr.	+.143	+.112	+.162	+.069	+.123	—.214*	+.002
25	Weight per 1,000 seeds, gm.	+.501**	+.469**	+.571**	+.469**	+.478**	—.138	+.039
26	Protein, %	—.279**	—.257**	—.299**	—.434**	—.331**	+.157	—.183*
27	Alcohol soluble nitrogen, %	—.317**	—.305**	—.330**	—.492**	—.394**	+.153	—.163
28	Oil, %	—.049	—.011	+.030	—.110	—.063	+.028	+.063

Range, mean, and standard deviation of 145 inbred lines

Range							
Lowest	59.000	60.000	99.000	42.000	10.000	0.000	0.000
Highest	93.000	97.000	148.000	95.000	49.000	88.000	66.000
Mean	75.861	77.943	123.492	65.119	27.934	17.664	8.844
Standard deviation	6.814	7.204	10.511	10.067	8.904	17.044	10.645

* Exceeds the 5 percent level of significance of 0.174.
** Exceeds the 1 percent level of significance of 0.228.

TABLE 10. — CORRELATIONS AMONG 28 CHARACTERISTICS OF 145 INBRED LINES *(continued)*

Code	Character	8	9	10	11	12	13	14
1	Days to half pollen	+.025	—.049	+.077	—.166	—.542**	—.056	—.245**
2	Days to half silk	+.023	—.009	+.102	—.153	—.534**	—.042	—.222**
3	Days to maturity	+.077	—.062	+.098	—.186*	—.559	—.066	—.211*
4	Plant height, in	+.215*	+.031	+.248**	—.218*	—.396**	—.011	—.152
5	Ear height, in.	+.059	+.001	+.204*	—.216*	—.537**	—.041	—.139
6	Root-lodged plants, %	—.060	—.038	+.133	+.132	+.255**	—.040	+.260**
7	Stalk-lodged plants, %	—.059	+.216*	+.055	—.059	—.162	—.086	+.149
8	Plot yield, lb.		+.164	+.125	—.205*	+.250**	—.189*	—.292**
9	Ears per plant, no.	+.164		+.025	—.112	+.137	—.029	—.061
10	Reaction to 2-4D, gr.	+.125	+.025		—.012	—.111	—.150	—.064
11	Mg. deficiency, gr.	—.205*	—.112	—.012		—.014	+.144	+.087
12	*H. turcicum*, gr.	+.250**	+.137	—.111	—.014		+.017	—.081
13	*H. maydis*, gr.	—.189*	—.029	—.150	+.114	+.017		+.001
14	Diplodia stalk rot, gr.	—.292**	—.061	—.064	+.087	—.081	+.001	
15	Gibberella stalk rot, gr.	—.200*	+.050	—.076	+.195*	+.091	+.036	+.267**
16	Smutted plants, %	—.069	+.002	+.162	+.077	+.211*	+.028	+.186*
17	Kernel rot, gr.	+.244**	+.003	—.074	—.049	+.122	+.080	—.128
18	Eur. borer oviposition, gr.	—.037	—.029	—.201*	—.070	—.018	+.056	+.059
19	Eur. borer leaf feeding, gr.	—.013	—.028	+.035	—.112	+.226*	—.048	+.168
20	Eur. borer plant injury, gr.	—.265**	+.038	—.029	+.035	+.184*	+.147	+.123
21	Eur. plant tolerance, gr.	—.351**	+.086	—.093	+.066	+.161	+.137	+.202*
22	Corn ear worm, gr.	+.123	+.234**	—.072	—.022	+.245**	+.029	+.031
23	Leaf aphids, index	+.106	—.127	+.077	—.064	—.297**	—.285**	—.144
24	Thrips, gr.	—.158	—.151	—.070	+.084	—.169	+.155	+.002
25	Weight per 1,000 seeds, gm.	+.031	—.102	+.112	—.097	—.308**	—.007	—.074
26	Protein, %	—.522**	—.096	—.092	+.328**	—.007	+.019	+.329**
27	Alcohol soluble nitrogen, %	—.427**	—.084	—.095	+.304**	+.040	—.079	+.283**
28	Oil, %	+.051	+.121	—.126	+.014	+.038	+.106	—.047

Range, mean, and standard deviation of 145 inbred lines

Range							
Desirable	14.200	1.92	2.000	0.500	1.000	0.500	1.600
Undesirable	2.100	0.65	5.000	5.500	5.000	5.000	5.000
Mean	8.525	1.172	3.754	2.666	4.398	2.996	2.900
Standard deviation	2.216	0.224	0.852	0.969	0.958	1.033	0.635

* Exceeds the 5 percent level of significance of 0.174.
** Exceeds the 1 percent level of significance of 0.228.

TABLE 10. — CORRELATIONS AMONG 28 CHARACTERISTICS OF 145 INBRED LINES *(continued)*

Code	Character	15	16	17	18	19	20	21
1	Days to half pollen	—.412**	—.315**	+.015	+.079	—.323**	—.234**	—.275**
2	Days to half silk	—.394**	—.294**	+.030	+.111	—.339**	—.274**	—.305**
3	Days to maturity	—.439**	—.305**	+.036	+.096	—.279**	—.233**	—.282**
4	Plant height, in	—.322**	—.244**	+.133	+.040	—.122	—.256**	—.294**
5	Ear height, in.	—.389**	—.270**	+.066	+.084	—.153	—.187*	—.239**
6	Root-lodged plants, %	+.198*	+.339**	—.112	—.185*	+.151	+.154	+.217*
7	Stalk-lodged plants, %	—.022	—.033	—.094	+.160	+.022	+.090	+.120
8	Plot yield, lb.	—.200*	—.069	+.244**	—.037	—.013	—.265**	—.351**
9	Ears per plant, no.	+.050	+.002	+.003	—.029	—.028	+.038	+.086
10	Reaction to 2-4D, gr.	—.076	+.162	—.074	—.201*	+.035	—.029	—.093
11	Mg. deficiency, gr.	+.195*	+.077	—.049	—.070	—.112	+.035	+.066
12	*H. turcicum*, gr.	+.091	+.211*	+.122	—.018	+.226*	+.184*	+.161
13	*H. maydis*, gr.	+.036	+.028	+.080	+.056	—.048	+.147	+.137
14	Diplodia stalk rot, gr.	+.267**	+.186*	—.128	+.059	+.168	+.123	+.202*
15	Gibberella stalk rot, gr.		+.104	—.051	+.019	+.036	+.225**	+.355**
16	Smutted plants, %	+.104		—.039	—.143	+.302**	+.215*	+.166
17	Kernel rot, gr.	—.051	—.039		—.029	+.016	—.075	—.129
18	Eur. borer oviposition, gr.	+.019	—.143	—.029		+.014	+.010	+.022
19	Eur. borer leaf feeding, gr.	+.036	+.302**	+.016	+.014		+.344**	+.311**
20	Eur. borer plant injury, gr.	+.225*	+.215*	—.075	+.010	+.344**		+.884**
21	Eur. plant tolerance, gr.	+.355**	+.166	—.129	+.022	+.311**	+.884**	
22	Corn ear worm, gr.	+.018	+.176*	+.268**	+.012	+.128	+.039	+.053
23	Leaf aphids, index	—.200*	—.053	—.045	+.098	—.215*	—.111	—.164
24	Thrips, gr.	+.026	+.008	+.026	—.005	+.081	+.049	+.076
25	Weight per 1,000 seeds, gm.	—.202*	—.039	+.097	+.072	—.141	—.010	—.049
26	Protein, %	+.207*	+.269**	—.271**	—.026	+.142	+.262**	+.317**
27	Alcohol soluble nitrogen, %	+.206*	+.252**	—.211*	—.028	+.164	+.177*	+.214*
28	Oil, %	—.109	+.062	—.039	+.074	—.063	—.001	+.011

Range, mean, and standard deviation of 145 inbred lines

Range							
Desirable	1.000	0.000	1.000	1.000	1.000	1.000	1.000
Undesirable	4.500	35.000	6.000	5.000	5.000	5.000	5.000
Mean	3.089	6.770	2.115	3.008	3.000	3.205	3.074
Standard deviation	0.747	7.293	1.249	0.707	0.830	0.949	1.018

* Exceeds the 5 percent level of significance of 0.174.
** Exceeds the 1 percent level of significance of 0.228.

TABLE 10. — CORRELATIONS AMONG 28 CHARACTERISTICS OF 145 INBRED LINES *(concluded)*

Code	Character	22	23	24	25	26	27	28
1	Days to half pollen	—.304**	+.509**	+.143	+.501**	—.279**	—.317**	—.049
2	Days to half silk	—.265**	+.512**	+.112	+.469**	—.257**	—.305**	—.011
3	Days to maturity	—.284**	+.573**	+.162	+.571**	—.299**	—.330**	+.030
4	Plant height, in.	—.160	+.373**	+.069	+.469**	—.434**	—.492**	—.110
5	Ear height, in.	—.234**	+.452**	+.123	+.478**	—.331**	—.394**	—.063
6	Root-lodged plants, %	+.198*	—.227*	—.214*	—.138	+.157	+.153	+.028
7	Stalk-lodged plants, %	—.028	+.070	+.002	+.039	—.183*	—.163	+.063
8	Plot yield, lb.	+.123	+.106	—.158	+.031	—.522**	—.427**	+.051
9	Ears per plant, no.	+.234**	—.127	—.151	—.102	—.096	—.084	+.121
10	Reaction to 2-4D, gr.	—.072	+.077	—.070	+.112	—.092	—.095	—.126
11	Mg. deficiency, gr.	—.022	—.064	+.084	—.097	+.328**	—.304**	+.014
12	*H. turcicum*, gr.	+.245**	—.297**	—.169	—.308**	—.007	+.040	+.038
13	*H. maydis*, gr.	+.029	—.285**	+.155	—.007	+.019	—.079	+.106
14	Diplodia stalk rot, gr.	+.031	—.144	+.002	—.074	+.329**	+.283**	—.047
15	Gibberella stalk rot, gr.	+.018	—.200*	+.026	—.202*	+.207*	+.206*	—.109
16	Smutted plants, %	+.176*	—.053	+.008	—.039	+.269**	+.252**	+.062
17	Kernel rot, gr.	+.268**	—.045	+.026	+.097	—.271**	—.211*	—.039
18	Eur. borer oviposition, gr.	+.012	+.098	—.005	+.072	—.026	—.028	+.074
19	Eur. borer leaf feeding, gr.	+.128	—.215*	+.081	—.141	+.142	+.164	—.063
20	Eur. borer plant injury, gr.	+.039	—.111	+.049	—.010	+.262**	+.177*	—.001
21	Eur. plant tolerance, gr.	+.053	—.164	+.076	—.049	+.317**	+.214*	+.011
22	Corn ear worm, gr.		—.269**	—.118	—.112	—.119	—.050	—.059
23	Leaf aphids, index	—.269**		—.061	+.416**	—.126	—.140	+.074
24	Thrips, gr.	—.118	—.061		+.160	—.076	—.042	+.014
25	Weight per 1,000 seeds, gm.	—.112	+.416**	+.160		—.243**	—.306**	—.022
26	Protein, %	—.119	—.126	—.076	—.243**		+.885**	+.042
27	Alcohol soluble nitrogen, %	—.050	—.140	—.042	—.306**	+.885**		+.029
28	Oil %	—.059	+.074	+.014	—.022	+.042	+.029	

Range, mean, and standard deviation of 145 inbred lines

Range							
Desirable	0.500	0.000	1.000	119.000	16.100	6.500	5.800
Undesirable	4.100	191.000	5.000	370.000	9.700	1.700	2.700
Mean	2.264	74.762	2.328	224.090	12.329	1.065	4.538
Standard deviation	0.624	39.555	0.854	42.426	1.306	0.208	0.547

* Exceeds the 5 percent level of significance of 0.174.
** Exceeds the 1 percent level of significance of 0.228.

progeny. Jorgenson and Brewbaker (1927) concluded that selection of the most vigorous inbred lines was a desirable procedure from a practical stand point.

Jenkins (1929) reported on correlation studies with inbred and cross-bred strains of maize. He found that, within the inbred lines, yield was correlated significantly and positively with plant height, number of ears per plant, ear length, ear diameter, and shelling percentage; and it was correlated significantly and negatively with date of silking, shrinkage of the harvested ears, chlorophyll grade, and ear-shape index.

Within the F_1 crosses, yield was correlated significantly and positively with date of tasseling, date of silking, plant height, number of nodes per plant, number of nodes below the ear, number of ears per plant, ear length, ear diameter, and shelling percentage. It was correlated significantly and negatively with percentage of smutted plants, percentage of moldy ears, and ear-shape index.

Jenkins (1929) found significant positive correlations between yield of the single cross and the following characters in the parents: date of tasseling, date of silking, plant height, number of nodes per plant, number of nodes below the ear, number of ears per plant, ear length, ear diameter, and yield. It was correlated significantly and negatively with ear-shape index in the parents.

Hayes and Johnson (1939) reported that yields of top crosses were correlated positively with the following characters of the inbred lines: date silked, plant height, ear height, leaf area, pulling resistance, root volume, stalk diameter, total brace roots, tassel index, pollen yield, yield index, and ear length.

Jugenheimer (unpublished, 1947) found that grain yield, standability, and maturity of three-way crosses were correlated positively and significantly with the same characters of the S_1 inbred lines. These data are arrayed graphically in Figures 32, 33 and 34.

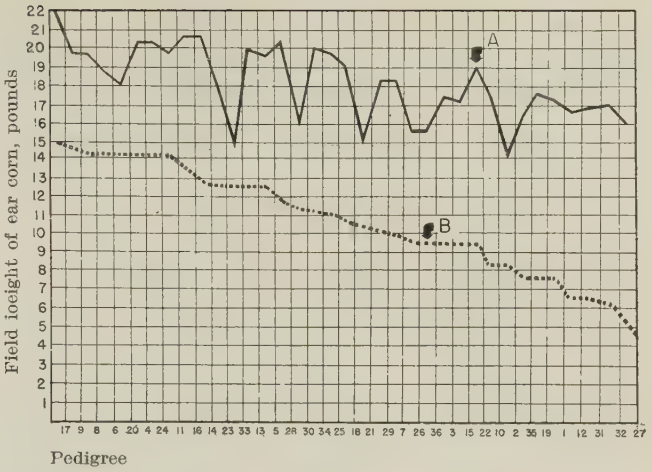
Evaluation of Lines by Hybrid Performance

Final evaluation of inbred lines can be determined best by hybrid performance. In earlier years of the maize breeding programs, inbred lines usually were not evaluated in hybrid combinations until they had been inbred for several generations. Many of the inbreds were divided into groups of about 10 lines. These were combined into all-possible single crosses, which were then tested in field trials. The lines were saved or discarded on the basis of the mean performance of the crosses. Since only 10 inbred lines were evaluated at a time, the need arose for a simpler, more rapid, and less expensive method.

FIGURE 32. - *Grain yield of three-way crosses was correlated positively with grain yield of the* S_1 *inbred lines. Correlation:* + 0.589.

KEY TO 3 GRAPHS

A. *Three-way crosses*
B. *Inbred lines.*



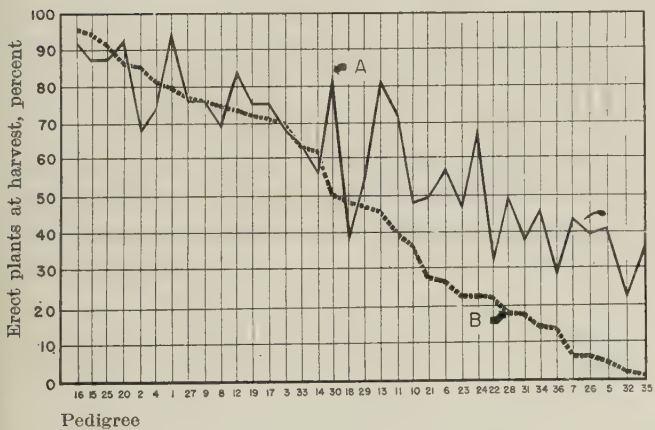


FIGURE 33. - *Standability of three-way crosses was correlated positively with standability of the* S_2 *inbred lines.*

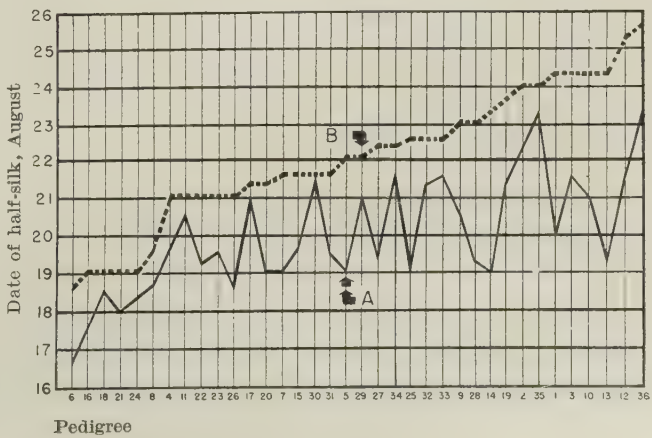


FIGURE 34. - *Maturity of three-way crosses was correlated positively with maturity of the* S_1 *inbred lines.*

(Courtesy, R. W. Jugenheimer, 1948)

A very large number of hybrids can be produced from a relatively few inbred lines. As shown below, over 11,750.000 different double-cross hybrids can be produced from only 100 inbred lines:

Lines	*Top crosses*	*Single crosses*	*Double crosses*
5	5	10	15
10	10	45	630
20	20	190	14 535
100	100	4 950	11 763 625
500	500	124 750	7 719 093 375
Formula:	n	$\frac{n\ (n-1)}{2}$	$\frac{3n\ (n-1)\ (n-2)\ (n-3)}{24}$

Jones (1922) reported on the relative performance of top crosses. Davis (1929) used top crosses to estimate the combining ability of S_2 lines. Lindstrom (1931) suggested the commercial use of top crosses. He found that certain inbred lines were very prepotent for ear type, disease resistance, standability, and uniformity of maturity.

Jenkins and Brunson (1932) found significant correlations between yields of inbred lines crossed *inter se* and the same lines as top crosses. They reasoned that the most valuable lines for use in double crosses, multiple crosses, or synthetic varieties are those which, on the average, produce the best hybrids when tested with a rather wide range of germ plasm. They determined whether this wide range of germ plasm might be supplied in one cross with a varietal mixture or a cross with an individual open-pollinated variety.

Correlations were determined between the mean performance of inbred lines in single crosses and topcrosses. Correlations involving 77 inbred lines were:

moisture at harvest, 0.80;
plant height, 0.52;
ear height, 0.71;
erect plants, 0.88;
smutted plants, 0.61;
stalks per plant, 0.74;
ears per cwt., 0.63;
shelling percentage, 0.86;
yield, 0.75.

Correlations above 0.24 were significant. Jenkins and Brunson (1932) concluded from their studies that crosses with standard open-pollinated varieties provide an efficient means for the preliminary testing of inbred lines for later use in other types of hybrid combinations.

The use of topcrosses provides an efficient method for the preliminary evaluation of inbred lines. They are especially useful for determining general combining ability of a large number of lines. Crossed seed may be produced in an isolated, detasseled crossing plot in which the open-pollinated variety or synthetic tester is used as the pollinating parent. Fifty percent or more of the inbred lines may be discarded on the basis of a preliminary test.

Testing inbred lines in three-way crosses is an efficient method where a desirable single-cross seed parent is available. The procedure permits the testing of a large number of inbred lines at one time, and eliminates the need for preliminary evaluation of inbred lines in top-crosses. The method, however, provides information primarily on specific combining ability. The actual procedure to be followed will be discussed more fully in Chapter 17.

Types of Testers

The type of tester to use for the evaluation of inbred lines in hybrid combination depends primarily on whether information is desired on general combining ability or specific combining ability.

General combining ability is the average performance of an inbred line in a number of hybrid combinations. General combining ability provides information on which inbred lines should produce the best hybrids when crossed with many other lines. The testers should be selected for their ability to determine which lines will combine well with many other lines. Because of their heterogeneity, open-pollinated varieties and synthetics are usually used for determining general combining ability.

Specific combining ability is the individual performance of an inbred line in a single specific hybrid combination. Suitable testers, therefore, may be used to determine which lines may be substituted in present hybrids or used in promising new hybrids. Obviously, information on specific combining ability will not provide reliable information on the relative usefulness of an inbred line when crossed with other testers. Desirable single-cross seed parents make excellent testers for determining specific combining ability.

Experimental evidence on general combining ability versus specific combining ability has been provided by Beard (1940) and Sprague and Tatum (1942). The latter workers divided the gene action concerned with combining ability between general and specific. They assumed that general combining ability was due to additive gene action, while specific combining ability was dependent on dominance, epistasis, and genotypic-environmental interactions. More extensive data are needed to verify or disprove their basic assumption.

Early Versus Late Testing

There is considerable diversity of opinion as to the best time of evaluating inbred lines of maize. Phases of the subject have been rather fully discussed by Jenkins (1935), Richey (1945, 1947, 1950), Sprague (1946, 1952, 1955), Jugenheimer (1948a, 1948b, 1950, 1954), Lonnquist (1950, 1951, 1953), Wellhausen (1952), Wellhausen and Wortman (1954), Hayes, Immer and Smith (1955), and others.

Proponents of late testing recommend that the inbred lines be self-fertilized for three to five years before evaluation in hybrid combinations. During this period, selection is practiced among and within progenies for general vigor, resistance to lodging, diseases, insects, and for other desired characteristics. These workers point out that the performance of inbred lines in crosses may change while they are becoming homozygous. Many of the inbred lines may be discarded during the inbreeding program on the basis of faults which contribute to the impracticability of their use in commercial production. Furthermore, the testing program is much more expensive and laborious than developing inbred lines.

Richey (1950) concluded that:

> "Test crosses are a good criterion of combining value at any stage in the program, as of that time. They are not good indicators of prospective combining value, however, until fixation has been reasonably achieved.
>
> Selfed performance on a progeny basis is not a good criterion of ultimate combining value until selection has eliminated recessives of larger individual effects and lower frequencies.
>
> With effective selection against recessives of major effect and progress toward fixation, progeny performance of selfs and of crosses will tend to tell more nearly the same story. Selfed performance then will be satisfactory for selecting within families, while crossed performance will be more suitable for selecting among families."

Early testing was suggested by Jenkins (1935). The advantages of early testing have been adequately described by Sprague (1946):

> "Early testing differs from the usual inbreeding and testing procedure in two main respects:
>
> 1. S_0 plants are outcrossed to a tester at the time of the first selfing. This tester parent (variety or double cross) usually is chosen specifically to reveal undesirable characteristics of the selfed plant, such as susceptibility to lodging, etc. Combining ability and general performance as measured in the test cross are the criteria used in determining whether further inbreeding of the tested S_0 plant is justified.
>
> 2. The heavy discarding of lines occurs after the first test before the individual lines involve any considerable investment in time or money.

Early testing is based on two assumptions:

1. There are marked differences in combining ability among the plants of a population selected for inbreeding;
2. A selected sample based on tests of combining ability of S_0 plants provides a better sample for further inbreeding and selection than does a more nearly random sample of combining abilities drawn from the same population on the basis of visual selection alone.

Limited evidence is available indicating the validity of each assumption."

A third group of maize breeders attempt a compromise between extremely early testing and extremely late testing. They limit evaluation of new lines to visual selection during the first year or two of inbreeding. Promising S_2 inbred lines are crossed with a suitable tester and evaluated in performance trials. The better performing inbreds may be re-evaluated in the S_3 or S_4 generations. Testing of siblings, traceable to the S_1, provides an opportunity for detecting significant segregation within families.

Locating Favorable Genes with Inversions

Dobzhansky and Rhoades (1938) suggested the use of inversions for locating favorable genes in maize. An inversion is a section of a chromosome which has been inverted or rotated by 180 degrees. Normal gene order in a chromosome may be represented as A B C D E F G H. An inversion of a block of genes may change the gene order to A B F E D C G H.

Inversions in maize may occur spontaneously or be produced by X-ray irradiation. An inbred strain carrying as many dominant mutant genes in as many different chromosomes as possible is treated with X-rays. The dominant genes will serve as chromosome markers. The irradiation will produce the inversions. Some of these inversions will include regions of different chromosomes marked by a dominant mutant gene. The extent of the inversions and their effects on crossing over must be determined genetically and cytologically.

The procedure for locating favorable genes in chromosome I of maize is shown in Figure 35 and outlined as follows:

First year. A homozygous inversion stock, carrying some suitable marker in the inverted section, is crossed with different inbred lines. The dominant marker might be the dominant P gene, which is responsible for colored pericarp. The homozygous inversion stock is used as seed parent and the inbred to be tested, which involves non-colored pericarp (pp), is used as pollen parent.

Second year. The F_1 is backcrossed to the inbred parent.

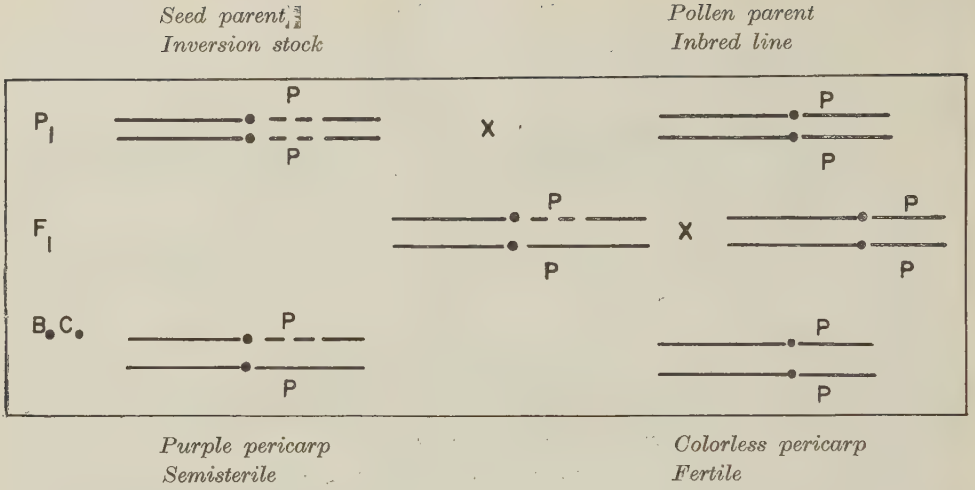


FIGURE 35. - *Procedure for locating favorable genes in maize with inversions.*

Third year. The seed produced in the second year is planted. A back cross of the F_1 plants to the inbred parent results in a segregation of a 1:1 ratio of plants homozygous and heterozygous for the inversion. The members of the two classes will occur at random within the progeny. Differences in yield, standability, or other characteristics between the homozygous and heterozygous progeny plants will be due to the differential influence of the genes carried on the inverted and normal segments of chromosome I.

Dobzhansky and Rhoades (1938) point out that if the

"recessive class yields 10 bushels per acre less than the dominant class when inbred A is used, and only five bushels less when inbred B is involved, the data shows significantly that inbred B carries a more favorable assemblage of genes in its chromosome I than inbred A does."

Back crosses to the inbred parent necessitate the use of an inverted stock carrying a dominant marker, or else all plants in the trial must be classified for pollen abortiveness. If the inverted stock does not carry a dominant marker, the plants must be classified for pollen abortiveness. The back crosses can be made to the inversion stock and the agronomic difference between the two classes be attributed to genes within the inverted segment of the inbred.

A complete analysis of the yielding ability and other characteristics of the genotype of any inbred line could be made if inversions were available covering all regions of the 10 chromosomes of maize. The inversion method of locating favorable genes in maize appears to be feasible (Sprague

1941). However, it is complicated and requires the development and use of a minimum of 20 special inversion stocks. The procedure may not be accurate for measuring small differences between any two inbred lines (Singleton 1941). However, the method is of value for basic, intensive research but is not likely to be widely used by maize breeders in programs to develop inbred lines.

Multiple Recessive Method

Singleton (1949) proposed a multiple recessive method for locating favorable genes. The inbred line is crossed with multiple recessive characters on each of the 10 chromosomes. The procedure might be outlined as follows:

First year. A stock containing multiple recessive characters on each of the 10 chromosomes is crossed with the inbred line to be evaluated.

Second year. The F_1 plants are self-pollinated to recover the recessive genotype.

Third year. Recessive plants are again backcrossed to the inbred line and the multiple recessive again reisolated.

Fourth to sixth years. After three or four back crosses, homozygous dominant and homozygous recessive stocks are obtained which are isogenic except for the marked chromosome.

Seventh year. Dominant and recessive types are crossed with the inbred line to be evaluated.

Eighth year. The two F_1 progenies are compared. Any excess in yield or improvement in other traits of the dominant plants over the recessive plants should be due to the inbred line being tested. All 10 chromosomes can be tested in this manner.

The multiple recessive method may have value. However, none of the chromosomes can be sufficiently marked to eliminate double crossovers. The method also involves three or four years of preparation before the tests can be made. Therefore, the method appears to involve too much time and labor to be practical at the present time.

PART III

Breeding for Specific Characteristics

10. MISCELLANEOUS FACTORS

Maize breeders must incorporate many desirable characteristics into their hybrids. Important traits needing consideration include high yields; proper adaptation; standability; harvestability; and resistance to heat, drought, cold, and chemical weed sprays.

Yield of Grain, Silage, Green Feed, and Fodder

Desirable hybrids must consistently provide high yields of grain, silage, green feed, or fodder. High yields from present maize hybrids are due to good combination of average-sized plants. Jenkins (1948) pointed out that hybrid plants are actually less vigorous than many of the superior plants that commonly occur in the open-pollinated varieties. It is entirely possible, therefore, that higher yielding hybrids may be produced when the proper combinations of genes are brought together.

Theoretically, multiple-eared plants should be more efficient than single-eared types, since a smaller percentage of the plants' energy might be required for plant development compared to ear development. Actually single-eared types are most popular. Non-tillering types are preferred for grain production; heavy tillering strains are useful for silage and green feed.

Number and size of kernels contribute to grain yield. Number of kernels is determined by the length of ears, number of rows per ear, number of ears per plant, and number of plants per unit area.

Leng (1953) found that F_1 hybrids exceeded their inbred parents by wide margins in total grain yield, weight of grain per ear, number of kernels per ear, and number of kernels per row. Hybrids exceeded their "top parents" by a relatively small but statistically significant margin in mean kernel weight, were almost identical with the "top parents" in mean row number, and significantly lower than the "top parent" in mean number of ears per plant. Hybrids, involving one or two parents having 18 or more rows, usually did not show heterosis in row number, while hybrids involving parents with less than 16 rows nearly always showed heterosis for row number.

Many other plant and ear characters also affect yield. Correlations shown in Table 10 (page 100) indicate that the taller, disease-resistant, insect-resistant inbred lines tended to be slightly higher yielding than their opposites. Estimates of heritability have been reported by Robinson, Comstock, and Harvey (1949) and Wärner (1952).

Genetics of yield is quantitative and controlled by many genes. Maize breeders will probably not be able to obtain the highest possible yields until they have a better understanding of the inheritance of quantitative characters and the nature and cause of hybrid vigor. The subject of heterosis is discussed in Chapter 4.

Maturity

Some hybrids must be extremely early in maturity in order to provide a high yield of sound grain within the limits of the growing season. Later maturing hybrids are needed in other areas to take full advantage of extremely long growing seasons. Fortunately, hybrids differ greatly in maturity. For example, in 1952 the hybrids in the FAO tests represented a relative maturity range from 70 to 155 days. These ratings were computed as the number of days from emergence to maturity. Locations of the tests ranged from Vidarshov, Norway, at a latitude of 60° 48′ North, to Sids, Egypt, at 28° 54′ North (Jugenheimer and Silow, 1954).

Various measures of maturity are used by different workers. These include:

1. days from planting or emergence to silking or tasseling;
2. percentage of dry matter or moisture in the grain at harvest;
3. days from planting or emergence to maturity;
4. heat unit sum.

Number of days from emergence to mid-silking or mid-tasseling is a very useful criterion of maturity in maize. The inbred lines in Table I in the Appendix ranged from 60 to 97 days between planting and half-silk.

Percentage of moisture in the grain at the time of harvest is a very useful measure of maturity. Several replications should be sampled in determining the moisture content of grain at harvest. Samples may consist of the entire plot yield or about 30 ears per entry selected at random. Entire ears may be shelled, or each ear may be sampled by removing about two rows of kernels. Electric moisture meters provide a rapid, accurate determination of the moisture content of the grain.

Maturity ratings by days vary considerably because they are greatly affected by such factors as temperature, length of days and growing season,

rainfall, rate and date of planting, and soil fertility. The stage of maturity as interpreted by various workers in the different countries also may not be exactly the same. Days to maturity of the inbred lines in Table I in the Appendix ranged from 99 to 148.

The " specific heat unit sum " is obtained by multiplying the average length of day by the average temperature and by summation of these products over the whole phenological period under consideration (Ferwerda, 1953). Ferwerda pointed out that a number of hybrids were grown by Stolwjk at Wageningen, Netherlands, and by Angulo-Busquets at Saragossa, Spain. These two locations are approximately 11° of latitude apart, and the hybrids were grown under widely different climatic and edaphic conditions. Consequently, the hybrids at Wageningen required about 1½ times as long to reach a certain phase of development as at Saragossa. The specific heat unit sum required at the two locations was similar.

Becker *et al* (1954) reported on the specific heat unit sum of maize. They used four daily temperatures: maximum, minimum, 8.00 a. m., and 7.00 p. m. From each temperature a minimum growth temperature was subtracted, negative values being valued at 0, before the daily average was computed. They stressed the importance of knowing the minimum growth temperature below which no growth is perceptible.

Becker *et al* pointed out that a minimum growth temperature estimated too low results in too great a heat unit sum, whereas a minimum growth temperature estimated too high results in too small a heat unit sum. This error is due to considering ineffective temperatures or neglecting effective temperatures respectively. They also demonstrated that inbreds, hybrids, and open-pollinated varieties may have different minimum growth temperatures. They believe that late maturity may be correlated with a high minimum growth temperature and that early maturity is correlated with a low minimum growth temperature.

Aldrich (1942) used plant measurements as indices of relative and absolute maturity in maize. He found that maize was not mature until the percentage of dry matter in the grain was at least 65 percent. Percentage of dry matter in the grain was the best criterion of maturity, and number of days to mid-silking was the second-best criterion.

Official market grades in the United States provide that No. 2 maize grain may not contain more than 15.5 percent moisture. In order to provide comparable comparisons, grain yields of hybrids compared in performance tests usually are reported on the basis of 15.5 percent moisture.

Many of the countries in Northern Europe are more interested in maize for silage and green feed than for grain. Maturity of maize silage may be evaluated on the basis of yield of dry matter and proportion of stalks and ears. Yields of silage and green feed in Europe usually are reported in quintals of dry matter per hectare.

Comparing the maturity of new hybrids with that of standard hybrids has advantages over attempting to classify hybrids in terms of days to maturity. The nine maturity classes and type hybrids used by workers in north-central and northeastern United States and in Europe and the Mediterranean countries are listed in Table 11.

TABLE 11. — NINE MATURITY CLASSES AND TYPE HYBRIDS RECOMMENDED FOR USE AS MATURITY STANDARDS

Maturity class	Type of hybrid used by workers in:	
	North-central and Northeastern United States	Europe and Mediterranean countries
100 - 199	—	W 1600
200 - 299	W 240	W 240
300 - 399	W 355	W 355
400 - 499	W 464A	W 464
500 - 599	OhM 15	OhM 15
600 - 699	OhK 24	Ia. 4316
700 - 799	Ia. 4297	Ind. 416
800 - 899	U.S. 13	U.S. 13
900 - 999	Mo. 804	U.S. 523W

Soil Fertility and Plant Population

Desirable production practices must go hand in hand with the use of adapted maize hybrids. Food for plants is just as necessary as food for humans and animals. Genes for high yield of desirable hybrids can reach their fullest expression only when the plant is grown on soils well supplied with balanced amounts of plant food. Maize grown on the Morrow plots at the University of Illinois for more than 75 years ranges in yield from about 15 bushels per acre on the untreated, continuous maize plot to more than 100 bushels per acre on the maize-oats-clover plot that has been given suitable amounts of fertilizer (Figure 5, page 17).

The number of plants per unit area of land must be adjusted to the productivity of the soil and water supply. Extensive investigations have shown that it is possible to develop hybrids adapted to different levels of soil fertility and plant populations. However, they must also be superior in their resistance to lodging and drought.

Differential responses of maize strains to different levels of maturity have been reported by Bryan, Jugenheimer and Pierre (1938). Dungan *et al* (1946), compared hybrids on two widely differing levels of fertility. The average yield for all hybrids on the better land was 125 bushels an acre. On the less fertile area, the average yield was 66 bushels an acre.

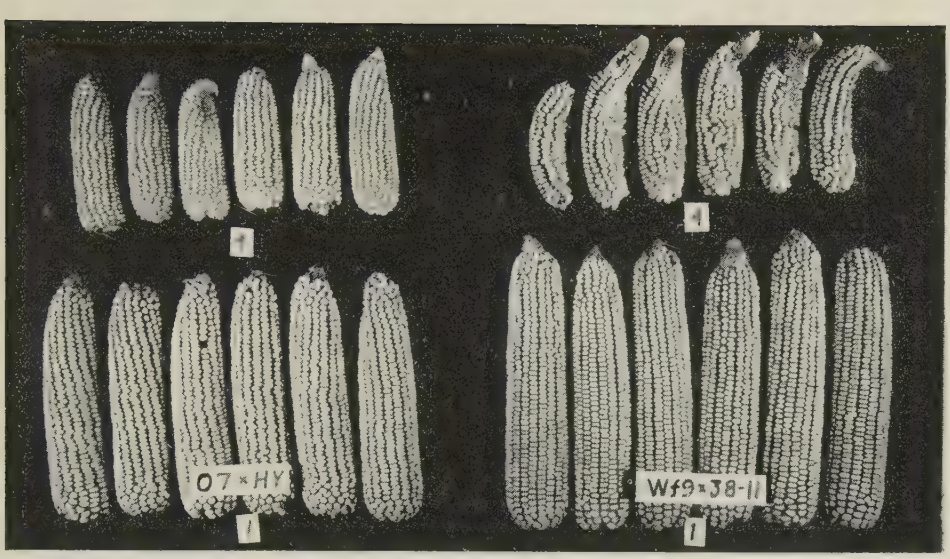


FIGURE 36. - *Hybrids behave differently under competition for nitrogen. The two hybrids shown here, WF9 × 38-11 and Hy × 07, were grown on land having a limited supply of nitrogen. When planted at the rate of one stalk per hill, both got enough nitrogen and WF9 × 38-11 proved distinctly superior to Hy × 07 in length of ear and total yield. When planted 4 stalks to the hill, Hy × 07 was superior to WF9 × 38-11 both in ear and kernel characteristics and in yield.*

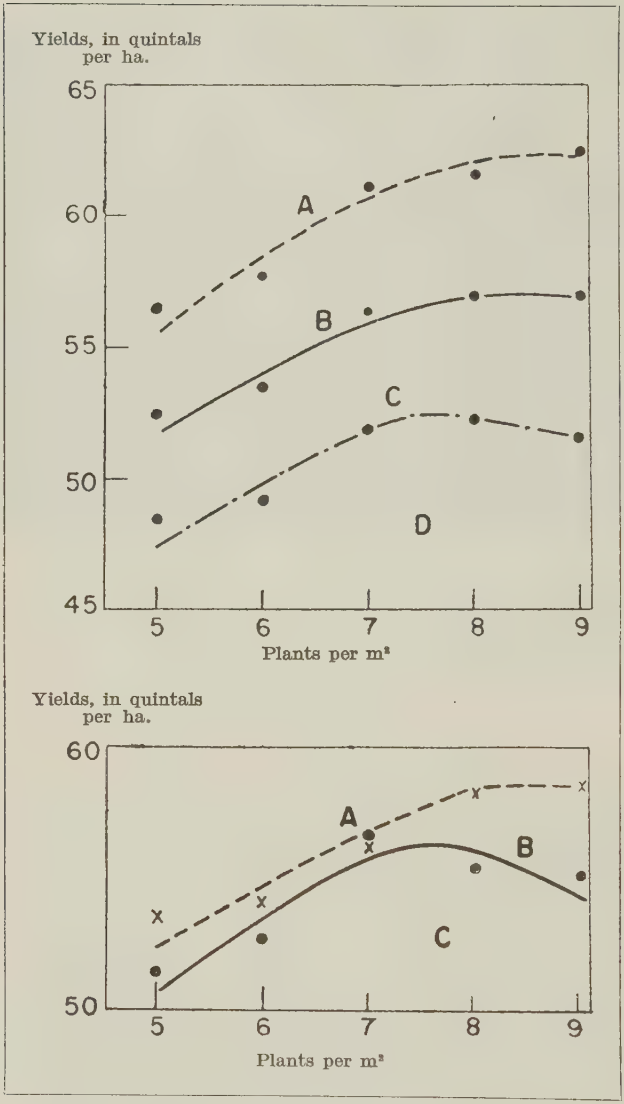
(Courtesy, Dungan, G. H. 1946)

WF9 × 38-11, a single-cross hybrid, showed a striking difference in response on the two soils. On the better soil, it yielded one bushel above the average yield of all hybrids in the field. On the poor soil, it was nine bushels below the average.

Figure 36 illustrates how hybrids may behave differently under competition for nitrogen. The two hybrids were grown at Urbana, Illinois, U.S.A., on land having a limited supply of nitrogen. When planted at the rate of one stalk per hill, both got enough nitrogen, and WF9 × 38-11 proved distinctly superior to Hy × 07 in length of ear and total yield. When planted at the rate of 4 stalks to the hill, Hy × 07 was superior to WF9 × 38-11 in yield and in ear and kernel characteristics.

Harvey (1939) studied the absorption and utilization of nitrogen ionic forms by growing inbreds and hybrids in aqueous mineral solutions. The strains of maize differed greatly in response. Efficient utilization of ammonium nitrogen appeared to be a partially dominant trait.

Extremes in magnesium deficiency of 145 inbred lines are shown in Table 1 in the Appendix. This deficiency appears to be associated with maturity, plant and ear height, grain yield, Gibberella stalk rot, and protein content of the grain (Table 10, page 100).



A. *Canbred 210*
B. *Average of varieties and row distances*
C. KE_3
D. *Averages of row distances.*

FIGURE 37. - *Effects of plant populations and row distances on yields of maize in the Netherlands.*

(By W. R. Becker, compiled by R. W. Jugenheimer and R. A. Silow, 1954)

A. *67-centimeter row distance*
B. *100-centimeter row distance*
C. *Averages of varieties.*

Various cultural practices affecting maize yields in the United States were reviewed by Kiesselbach (1950), Miles (1952), and Rost (1954). Miles suggested that, with most hybrids, one kernel should be planted per hill for each 25 bushels of potential yield. Early maturing hybrids should be planted at the rate of one kernel for each 20 bushels of anticipated yield. For maximum yields, the maize should be planted thickly enough so that the average size of the ear is approximately one-half pound at harvest. Large ears are secured only by sacrificing considerable yield.

Lang, Pendleton and Dungan (1956) found that protein and oil con-

A. *Average of Canbred 210 and KE_3.*

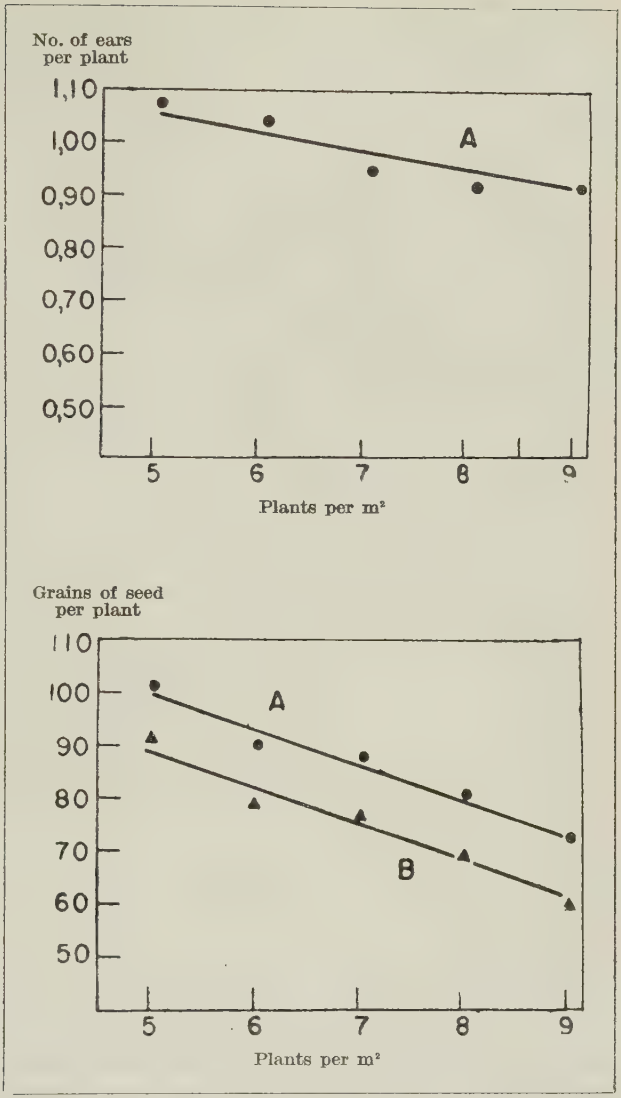


FIGURE 38. - *Effects of plant population on the number of ears and seed yield per plant in the Netherlands.*

(By W. R. Becker, compiled by R. W. Jugenheimer and R. A. Silow, 1954)

A. *Canbred 210*
B. *KE_3.*

tent of the grain decreased with higher plant populations and lower nitrogen levels. Hybrids which tended to be multiple-eared at low population rates had the lowest percentage of barren stalks at the high plant populations. Highest yields were obtained when ear weight averaged 0.54 of a pound.

Becker and others discussed " Spacing and Population Studies with Maize " at the Sixth FAO Hybrid Maize Meeting held in Portugal in 1953 (Jugenheimer, Kjaer, and Silow, 1953). The effects of plant populations and row distances on grain yields in the Netherlands are shown in Figure 37.

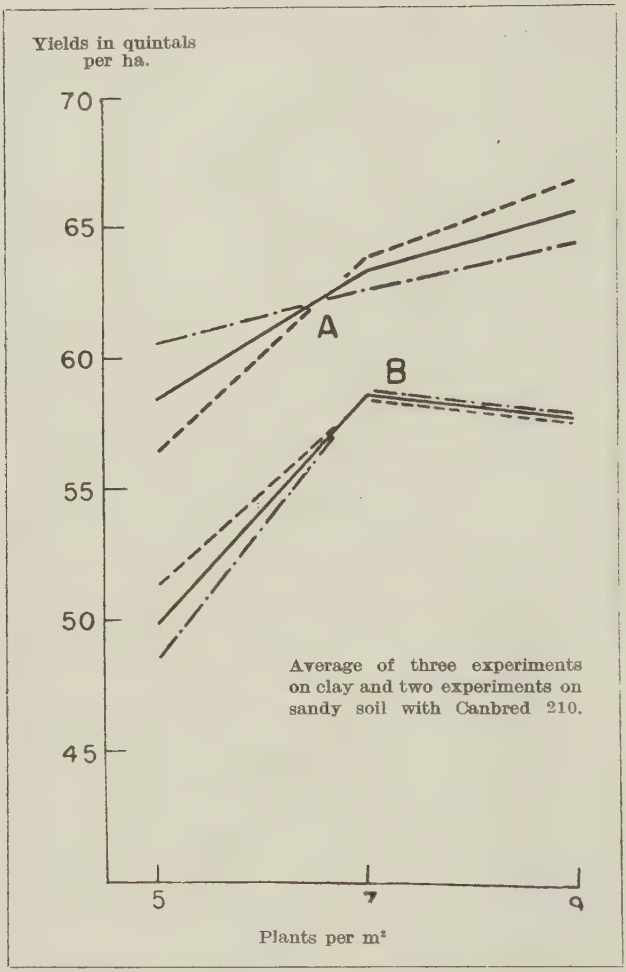


FIGURE 39. - *Effects of plant populations and row distances on yields of Canbred 210 grown on clay and sandy soils in the Netherlands.*

(By W. R. Becker, compiled by R. W. Jugenheimer and R. A. Silow, 1954)

Row distance

- *67-centimeter*
- *100-centimeter*
- *Average*

A. *Clay*
B. *Sand.*

This experiment included five plant populations, two row distances, and two hybrids. The best plant population was seven to eight plants per square meter.

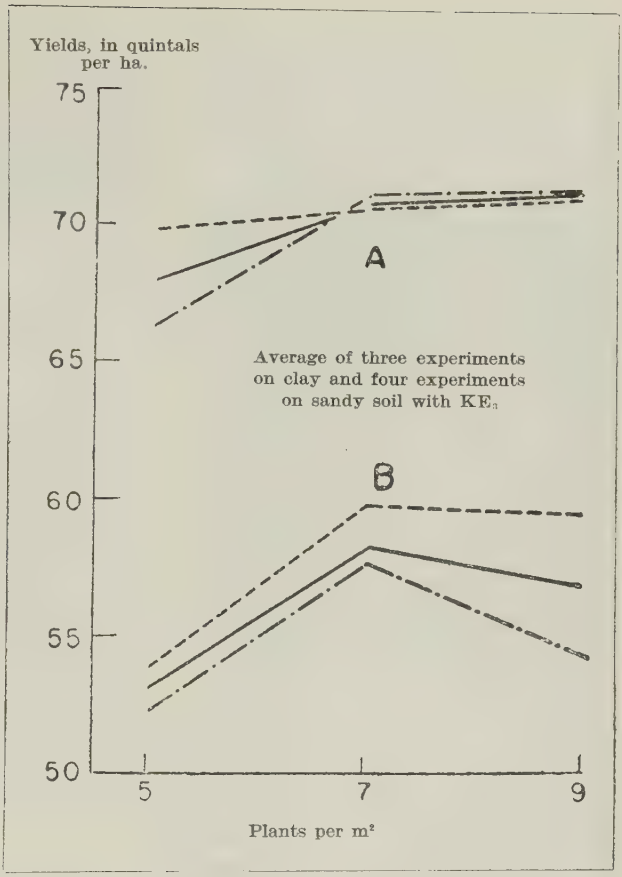
The influence of plant density on the number of ears per plant and on seed yield per plant are shown in Figure 38. Seed yield was affected more than the number of ears.

Figure 39 shows the results of five spacing experiments with Canbred 210. In these experiments, there was a highly significant yield difference in favor of clay soils over sandy soils.

The effects of plant populations and row distances on grain yields at seven locations are shown in Figure 40. Highest yields were obtained on the clay soils and with a population density of seven plants per square

FIGURE 40. - *Effects of plant populations and row distances on yields of KE_3 grown on clay and sandy soils in the Netherlands.*

(By W. R. Becker, compiled by R. W. Jugenheimer and R. A. Silow, 1954)



meter. Based on results obtained during the past several years, the following recommendations were made to Dutch farmers:

1. Plant enough seed to obtain a population of seven plants per square meter, and thin to the desired stand.
2. Increase the space between rows to 85 centimeters or a meter to fit farming methods.

Wider spacing between rows usually results in greater yield, better standability, successful legume seedings, and lower cost of production.

Maize is usually planted more thickly in European countries than in America. American farmers are primarily interested in the ear. The plants are usually plowed under for organic matter. European farmers are usually interested in the entire plant. Consequently, barrenness and smaller ears resulting from excessively thick planting is not considered serious, inasmuch as the entire plant is used for feed.

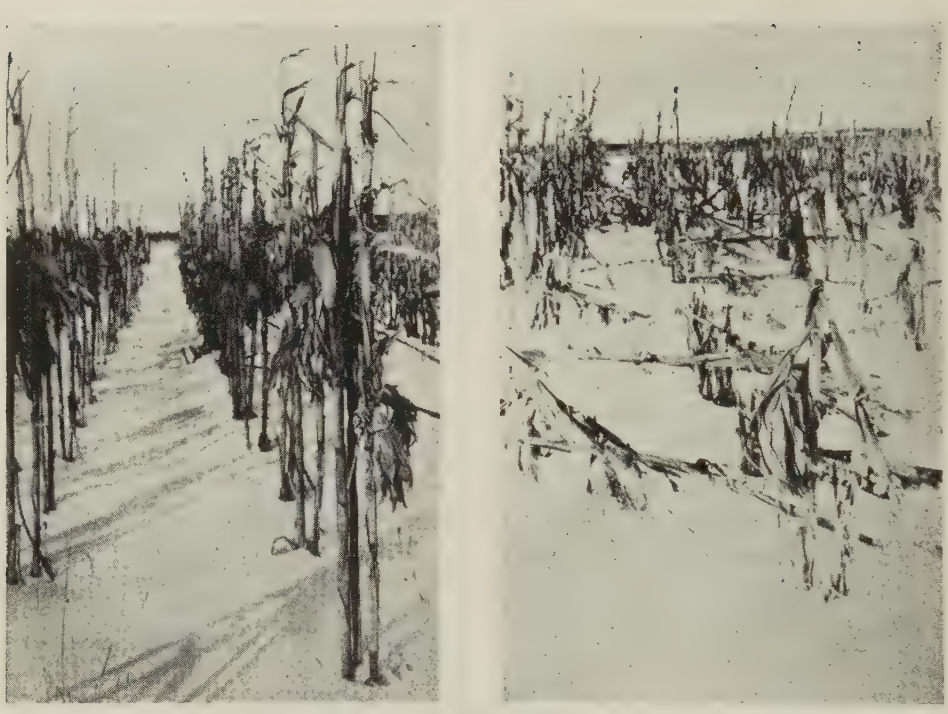


FIGURE 41. - *Hybrids differ markedly in strength of stalks and roots. These pictures of two hybrids growing in the same field were taken on the same day.*
(Courtesy, A. A. Bryan and R. W. Jugenheimer, 1937)

Standability

Weather is one of the great natural hazards of crop production. Enormous savings could be effected by developing maize hybrids that were highly resistant to lodging, heat, drought, cold, and mechanical injury. Resistance is the ability of a plant to remain relatively unaffected by abnormal environmental influences because of inherent properties it possesses.

Excellent standability has contributed greatly to the popularity of maize hybrids (Figure 41). Lack of standability results in lowered quality, decreased yield and in more difficult harvesting. Variations in standability among hybrids are caused by such things as differences in resistance to diseases and insects, stalk structure, root system, ear height, soil fertility, and plant population. Plant characters associated with root and stalk lodging are shown in Table 10, page 100.

Diseases and insects probably are responsible for more stalk breaking and root lodging than any other single factor. Diseases like *Diplodia zeae* and *Gibberella zeae* cause the stalk to rot and fall. European corn borers tunnel into the plant and cause it to break. Chinch bugs sap the plant and cause it to wither and die. Fortunately, procedures have been developed

to aid in obtaining hybrids with greater resistance to these hazards. Such techniques for obtaining artificial disease infections and insect infestations are described in the Chapters 13 and 14, on diseases and insects.

Holbert and Koehler (1924), Koehler (1925), Wilson (1930), Pettinger (1933), and Hall (1934) pointed out that strains of maize differ in the force required to pull the plants from the soil. This technique makes it possible to determine differences in root strength independently of the weather.

Koehler (1925), and Wilson (1930) showed a positive relationship between lodging and the number of brace roots. Holbert (1924) reported a positive association between lodging and the number and branching of roots. He also pointed out that strong plants have roots with large oval trachoids and large pith cells.

Wilson (1930) found that short, lower internodes were associated with erect plants. Jenkins (1930) reported a rootless line which was unable to stand erect because of the scarcity of roots. Jenkins and Gerhardt (1931) reported a " lazy " gene that caused complete lodging due to negative geotropism.

The relationship between certain morphological characters and lodging in maize was studied by Hall (1934). He found that freedom from lodging was associated positively with lower ears, longer brace roots, wider and deeper root clumps, larger root volume, less disease, fewer suckers, and more pounds to pull the plant from the soil.

Hunter and Dalbey (1937) reported correlations between anatomical structure of the stalk and stalk breaking in the field (Figure 42). Strong-stalked inbred lines possessed thick layers of deeply stained schlerenchyma around

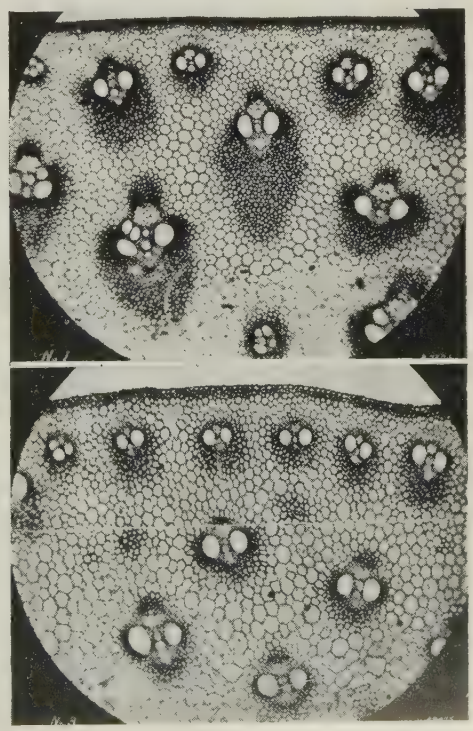


FIGURE 42. - *The strong-stalked inbred line (above) shows a deeper stained subepidermal layer and thicker layer of schlerenchyma tissue surrounding the vascular bundles than does the weak-stalked line (below).*

(Courtesy, J. W. Hunter and N. E. Dalbey, 1937)

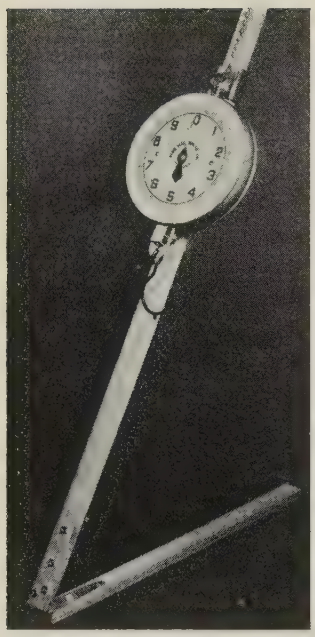


FIGURE 43. - *Machines may be used to determine the breaking strength of stalks in efforts to find lodging-resistant material.* (Courtesy, A. F. Troyer, 1956)

the vascular elements and the subepidermis and had angular cells with small intercellular spaces.

Machines have been developed to determine the breaking strength of stalks in an effort to find stiff-stalked material. Troyer (1956) studied the effect of Diplodia stalk rot on stalk breaking with the apparatus shown in Figure 43.

Heat and Drought Tolerance

Extremely high temperatures, especially when accompanied by deficient moisture, may be very injurious to maize. The plants appear to be most susceptible to injury by high temperatures at the tasseling stage. A combination of high temperature and low humidity may kill the leaves and tassel and prevent pollination.

Drought resistance is a complex phenomenon. The leaves of some inbred lines and hybrids are severely damaged by heat and drought, while others growing alongside may remain green and apparently undamaged throughout severe periods of heat and drought. Figure 44 shows a field planted for the production of single-cross seed in Kansas. The pollen parent, K151, in this field was severely injured by heat and drought, while the seed parent, 38-11, survived with little apparent damage. Inbred lines differ greatly in their resistance to heat and drought. Under drought conditions, the leaves of some inbred lines roll tightly like sorghum, others top-fire badly, while some remain green and turgid (Figure 45). Differences in resistance may be reported in grades or in percentage of leaf surface damaged. Plants of inbred lines in Table I in the Appendix ranged from 0 to 100 percent of drought damage.

Damaging effects of short periods of heat and drought often may be alleviated by early or late planting of especially developed strains. A more reliable remedy is the development and use of drought-resistant material. Fortunately, drought resistance is a hereditary trait. Table 12 shows differences in leaf firing prepotency of ten inbred lines as expressed in their single-crossed progenies. For example, inbred line K201C was prepotent for resistance to leaf firing, while Oh04 tended to be susceptible. Single cross Oh04 × K4 had 77 percent of fired leaf surface,

Figure 44 - The pollen parent, K151, in this seed production field was severely injured by heat and drought while the seed parent, 38-11, survived with little apparent damage.

(Courtesy, R. W. Jugenheimer, 1939)

FIGURE 45. — *Inbred lines differ greatly in their response to heat and drought. Under drought conditions, the leaves of some inbreds are rolled, others top fire badly, while some remain green and turgid.*

(Courtesy, R. W. Jugenheimer, 1939)

compared with 10 percent for most of the single crosses involving inbred line K201C. A difference of 21 percent was statistically significant at the 5 percent level.

The relative drought resistance of double-crosses can be predicted from single-cross data. The single crosses involved in Kansas Hybrids K1583 and K1585 were included in the test reported in Table 12. These two hybrids which are resistant to leaf firing were also included in the same test. Table 12 shows that the actual leaf firing of these two hybrids was practically the same as the predicted value.

TABLE 12. — RESISTANCE TO LEAF FIRING PREPOTENCY OF 10 YELLOW INBRED LINES AS EXPRESSED IN THEIR SINGLE-CROSS PROGENIES

Parent lines	ILL. R38	ILL. R40	Ind. 38-11	Kans. K4	Kans. Kys.	Kans. K201C	Mo. 940	Oh. 04	C.I. 3	C.I. 7	Hybrid	Performance	
												Actual	Predicted
	Percent of leaf surface fired												
ILL. R38	—	13	20	10	17	10	20	30	13	17	K 1583	17	15
ILL. R40	13	—	27	13	13	13	47	50	20	17	K 1585	17	12
Ind. 38-11	20	27	—	13	30	10	50	60	33	27	—	—	—
Kans. K4	10	13	13	—	10	10	33	77	17	10	—	—	—
Kans. Kys	17	13	30	10	—	10	27	33	20	13	—	—	—
Kans. K201C	10	13	10	10	10	—	10	10	10	10	—	—	—
Mo. 940	20	47	50	33	27	10	—	30	40	37	—	—	—
Oh. 04	30	50	60	77	33	10	30	—	53	43	—	—	—
C. I. 3	13	20	33	17	20	10	40	53	—	47	—	—	—
C. I. 7	17	17	27	10	13	10	37	43	47	—	—	—	—
Mean	17	24	30	21	19	10	33	43	28	25	—	—	
Rank	2	5	8	4	3	1	9	10	7	6	—	—	—

NOTE: A difference of 21 percent between any two single crosses is significant at the 5 percent level.
SOURCE: Jugenheimer, 1943.

Correlations between leaf firing and grain yield are shown in Table 13.

TABLE 13. — CORRELATIONS BETWEEN LEAF FIRING AND GRAIN YIELD, 1939

District number	Paired observations, number	r value	Level of significance	
			1 percent	5 percent
1	70	— 0.671**	0.305	0.232
2	70	— 0.214	0.305	.232
4	60	— 0.568**	0.325	.250
5	60	— 0.333**	0.325	.250

** Highly significant (1 percent level of significance).
SOURCE: Data from *Kansas Agricultural Experiment Station Bulletin 288.*

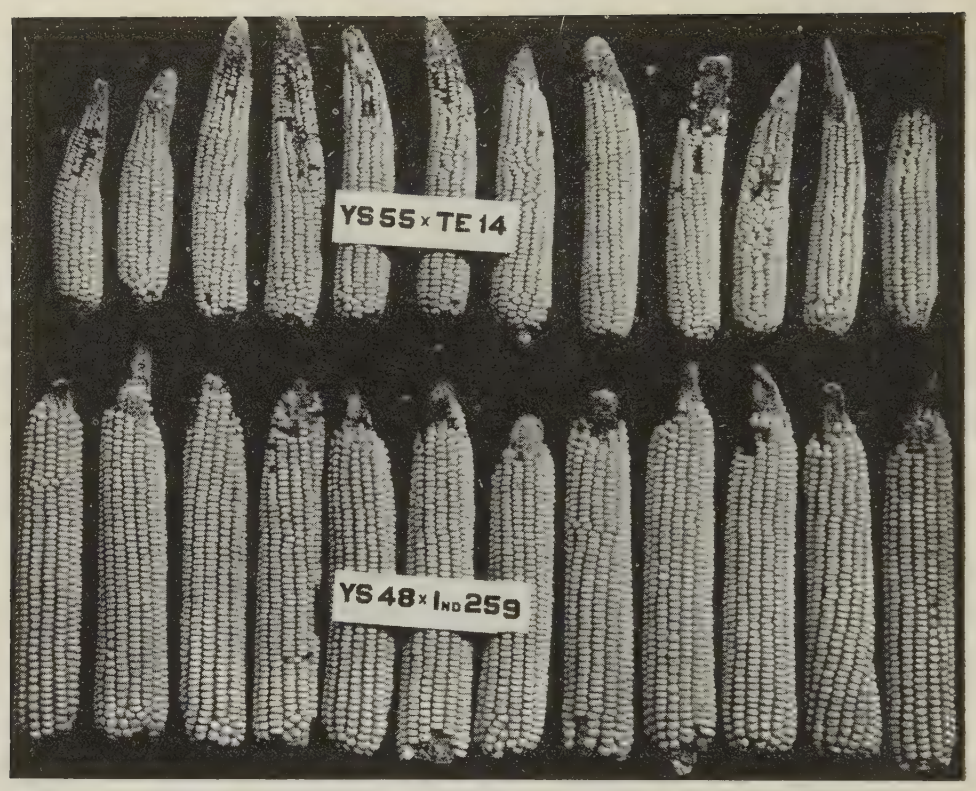


FIGURE 46. - *Both hybrids, of equal maturity, were grown side by side. After firing badly from heat and drought, YS55 × TE14 yielded 27 bushels per acre, while the YS48 × Ind.259 did not fire and yielded 66 bushels per acre.*

(Courtesy, R. W. Jugenheimer, 1939)

These correlations indicate that high leaf firing usually is negatively associated with high grain yield. However, numerous other climatic factors also affect grain yield. Figure 46 shows two hybrids of equal maturity which were grown side by side. After firing badly from heat and drought, hybrid YS55 × TE14 yielded 27 bushels per acre, while hybrid YS48 × Ind 259 did not fire and yielded 66 bushels per acre.

Tatum and Brooks (1954) found that top firing in maize was associated with restricted water movement in plant tissues. Water movement in the plant was studied by means of eosine dye solutions. Restricted water conducting capacity of the sheath and collar regions was found to be associated with wilting and firing. It appeared that delayed maturity of meta-xylem vessels was partially responsible.

Hunter, Laude and Brunson (1936), and Heyne and Laude (1940) were able to distinguish differences in drought tolerance among inbred lines by testing the seedling plants under controlled conditions. Results

obtained in the heat chamber correlated satisfactorily with results obtained with mature plants in the field. Heyne and Brunson (1940) showed that heat tolerance of seedling plants was a hereditary trait. These workers suggest that a heat chamber is a valuable aid in selecting material resistant to heat and drought.

Adverse weather during the critical flowering period is a considerable hazard to maize production in many areas. High temperatures may blast the entire tassel or kill the pollen grains after they are shed. It may also interfere with pollination by causing the silks to wilt rapidly thus hastening the loss of their receptivity to pollen. This interference with pollination is reflected in poorly-filled ears at harvest and consequently a reduction in the yield of grain.

Many hybrids that are resistant to leaf firing often yield more grain than susceptible types in years when droughts occur. Maize hybrids resistant to leaf firing, however, frequently produce low yields. It appears that the reduction in yield may be due to interference with normal fertilization as well as injuries sustained by the vegetative portion of the plant.

Factors affecting seed setting in maize were studied by Lonnquist and Jugenheimer (1943). Significant negative correlations were obtained between high temperatures and seed setting on inbred lines when self-pollinated. Some lines set seed well at the highest recorded temperatures while others set few seeds at relatively optimum temperatures. As an average of two years, seed setting ranged from 65 to 8 percent when the maximum temperature on the day of pollination ranged from 80° to 110° F. respectively (Figure 47).

Maximum seed setting was obtained when silks were exposed to pollen by two days after emergence, and it declined rapidly thereafter for each additional two-day period that pollen was withheld from the silks. Lines resistant to leaf firing, as well as the single-crosses among them, set more

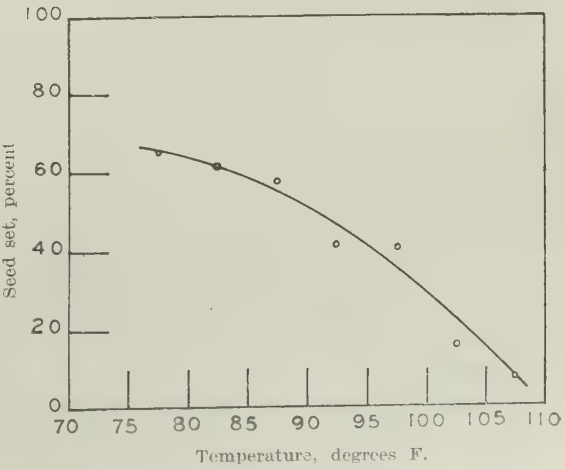


FIGURE 47. - *Percentage of ovules setting seed on ears of inbred lines of maize grown under irrigation and self-pollinated on days differing in their maximum temperature.*

(Courtesy, J. A. Lonquist and R. W. Jugenheimer, 1943)

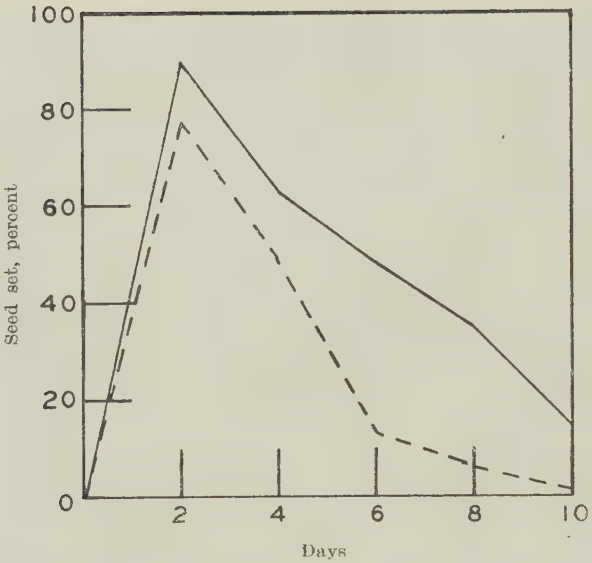


FIGURE 48. - *Duration of receptiveness of stigmas to pollen of six inbred lines of maize differing in resistance to leaf firing and compared on dry land and under irrigation.*

(Courtesy, J. A. Lonnquist and R. W. Jugenheimer, 1943)

Resistant
Susceptible.

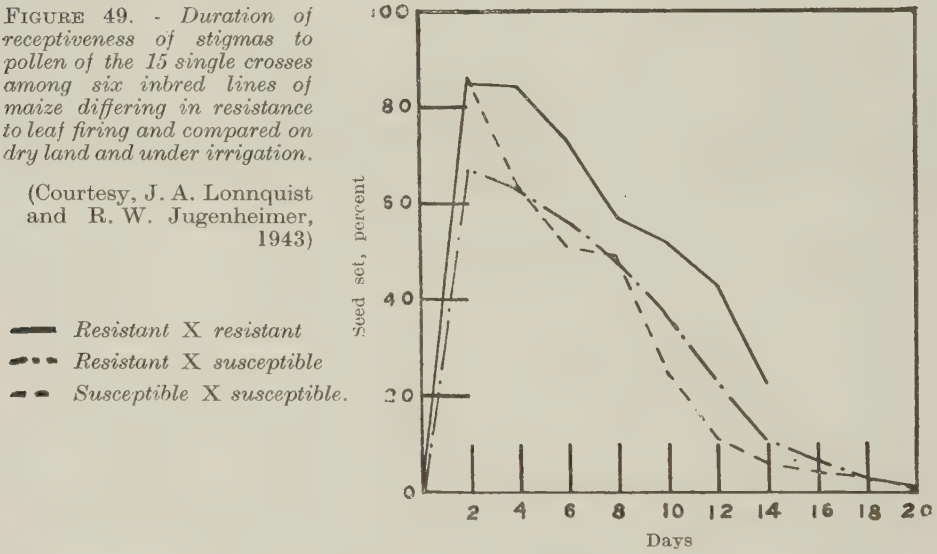


FIGURE 49. - *Duration of receptiveness of stigmas to pollen of the 15 single crosses among six inbred lines of maize differing in resistance to leaf firing and compared on dry land and under irrigation.*

(Courtesy, J. A. Lonnquist and R. W. Jugenheimer, 1943)

Resistant X *resistant*
Resistant X *susceptible*
Susceptible X *susceptible.*

seed throughout the life of the silks and remained receptive longer than did the susceptible lines and crosses (Figures 48 and 49). Loss of receptivity was more rapid in the inbred lines than in the single crosses. Adequate soil moisture provided by irrigation, together with the associated lower temperatures and higher humidity, was effective in prolonging silk receptivity.

Highly significant positive correlations were obtained between the rate of silk emergence and the percentage of seed set for successive two-day

intervals following initial silk emergence. Inbreds and hybrids whose silks remain receptive for longer periods have a specific advantage under heat and drought conditions.

TABLE 14. — DIFFERENTIAL FERTILIZING ABILITY OF POLLEN OF 25 INBRED LINES OF MAIZE WHEN PLACED ON SILKS OF THE SINGLE CROSS, WF9 × 38-11

Resistant to leaf firing		Susceptible to leaf firing	
Line	Percentage seed set	Line	Percentage seed set
K 201A	82.5	Ind. 66-24	89.0
K 148	72.5	K 26	79.0
K 17	72.5	K 14	75.0
K 8	71.0	Iowa B1 349	75.0
K 55	70.0	K 151	65.0
Ind. 38-11	67.0	K 20	62.0
K 130	65.0	K 214	60.0
U.S 187-2	63.0	K 5	51.0
Iowa L317	58.0	K 131	45.0
K 10	50.0	K 249	42.5
K 153	41.0	K 61	37.0
Ind. WF9	32.0		
K 18	14.0		
K 167	12.0		
Mean	55.2	Mean	61.9

Analysis of variance

Source of variation	D/F	Mean square
Leaf firing class	1	21.17
Lines	24	19.84**
Error	91	5.37

** Highly significant.
SOURCE: Lonnquist and Jugenheimer, 1943.

The differential fertilizing ability of pollen is shown in Table 14. Pollen of 25 inbred lines, placed the same day on randomly selected silks of the single cross WF9 × 38-11, gave highly significant differences in resulting seed set. Some of the differences obtained might have been due to varying degrees of cross-incompatibility existing between the pollen of various lines and the silks of the seed parent.

Tatum and Kehr (1951) also reported on factors affecting seed set of inbred lines. Success of hand pollinations on dent maize inbreds was found to vary from day to day, for different times of the day, and for different inbreds. There were no striking indications of a differential response of different inbreds to environmental conditions. There was evidence for a time of day by date interaction.

A very close relationship was found between pollination success and the temperatures and relative humidities which prevailed at the time

the pollinations were made. It was suggested that temperature and relative humidity influence pollination indirectly through their effects on evaporation and transpiration and, in turn, the internal water supply or turgidity of the plants. There was some indication that lack of sufficient moisture in silks to germinate pollen may be more important in causing poor seedset than is lack of viable pollen.

In areas with frequent periods of extreme heat and drought, the most desirable strains of maize over a period of years often have been those in which the individual plants varied considerably in date of silking and tasseling. Experimental evidence has shown that most hybrids pollinate over a shorter period of time than do the adapted open-pollinated varieties. Planting a mixture of two or more desirable hybrids or varieties differing in maturity is usually a desirable practice under heat and drought conditions.

Cold Tolerance

Many breeders are devoting special effort to finding maize strains with stronger germination, more vigorous emergence and early seedling growth in cold, wet soils; and which grow normally at relatively low temperatures. Such performance in the absence of seed-rotting organisms may be termed " spring cold tolerance ". Similar performance in the presence of soil organisms really is " disease resistance " but often is not differentiated from cold tolerance.

Inbred lines of maize differ greatly in reaction to so-called " cold tests " (Tables I and II in the Appendix) and kernel rotting (Tables III and IV in the Appendix).

Neal (1950) reported that a genetic mechanism was influencing the behavior of the material he studied. Disparity between results of refrigeration and field tests showed that pathological factors were involved. He concluded that cold tolerance is conditioned by a complex interaction of genetic and pathological factors involving physical, genetic, and physiological considerations. Like many others, he emphasized the importance of seed injury, maturity, frost, and age of seed on spring cold tolerance. Soil type and crop rotations affected the pathological flora of the soil. Seed and pollen parents were other factors in cold tolerance, since reciprocal hybrids often did not behave alike under cold test conditions.

In the report of the 1952 FAO Hybrid Maize Meeting, Bunting referred to the work of Wernham (1951) who showed that at least 17 different fungi cause seedling blight. Bunting pointed out that seed quality influences the results of low temperature incubation tests. Immature seed with a high moisture content at harvest, or seed damaged by frost is very susceptible to infection at low temperatures.

Low temperature incubation or " cold tests " have received consideration by maize workers. A review of such work is included in the report of the 1951 FAO Hybrid Maize Meeting. At the meeting, Jenkins pointed out that low temperature incubation tests give results that correlate well with germination obtained under field conditions. Large differences among inbred lines are transmitted to hybrids. The genetic nature of the inheritance is complex and influenced by a large number of environmental factors.

Hoppe (1955) explained that " cold tests " are germination tests made in soil that is kept cold during the early part of the germination period. The test actually is not primarily against cold, but rather against seed-rotting molds or fungi which inhabit nearly all soils and attack slowly germinating seeds in cold soil. He believes that species of *Pythium* are the principal fungi involved.

Pythium species differ in virulence and the severity of the test depends upon the species present in the soil. The " field " soil used in the test therefore must contain *Pythium*. The soil should not be allowed to dry out before it is used, since *Pythium* in dried samples becomes dormant and does not give a virulent test (Hoppe, 1955).

Rinke (1954) defined cold testing to mean a germination test in the presence of seedling blight organisms and under adverse moisture and temperature conditions. Factors affecting the cold test include:

1. disease organisms present in the soil;
2. amount of water used;
3. temperatures;
4. length of exposure;
5. environment of seed production;
6. maturity of seed;
7. mechanical damage to seed;
8. seed treatment.

The cold test procedures at Minnesota include:

1. *Unsterilized field soil.* Soil is taken from a maize field and mixed half and half with sand to improve its structure. Disease organisms are not added.
2. *Water.* Sufficient water is added to approach the soil saturation point. High relative humidity conditions are maintained in constant temperature chambers.
3. *Temperatures and length of exposure.* Forty-eight hours at 78° to 80° F.; six to 10 days at 47° to 48° F.; four days at room temperatures above 70° F.
4. *Mechanical damage* is minimized by using handshelled seed.
5. *Seed treated with Spergon.* This is an attempt to control seedling blight organisms, which might be present on the surface of the seed (Rinke, 1954).

A simple cold testing technique developed by Hoppe (1955) at the University of Wisconsin has been called the "rolled towel" method. This procedure consists of placing a thin layer of field soil upon a water-soaked paper towel. Seeds are placed germ side down on top of the soil. The towels are then rolled and stood on end in an aluminum container with a perforated bottom. A plastic cover is placed over the top of the pan to lessen evaporation. Excess water drains out of the bottom. The pans are placed in a household refrigerator at a temperature of approximately 50° F. for six to eight days, after which they are germinated at room temperature for three to four days.

The step by step procedure of the rolled towel method of cold testing maize seed was described by Hoppe (1955) as follows:

"A heavy wire screen placed over a sink, provides a good working surface on which to roll the wet towels because it remains clean. Other containers for draining away excess water may be devised if a sink is not available.

Usually three 50-kernel tests for each sample are made in each 'cold test'. Each lot should be counted out in small containers that will stack in piles of three without spilling the seed. Metal tops from jelly glasses are excellent for this purpose. Identify each 50-kernel lot with a number written with soft lead pencil on paper.

Wet two of the paper towels by immersing in a shallow pan of water. Lay one towel on top of the other on the screen with the longer dimension extending away from the worker. Place the label which identifies the sample, face down, between the towels in an upper corner. Sprinkle a thin layer of muck soil about $^1/_8$ inch deep on the towels leaving an inch or more uncovered around the margin and distribute the 50 kernels evenly over the soil. It is then sometimes necessary to add some more soil in thin spots although the kernels need not be covered. Finally, lay another wet towel over the soil and kernels. Then roll the whole into a paper 'doll,' being careful not to roll too tightly. Too tight rolling or too tight packing in the container can ruin a test. A container the size of the one described should contain no more than 21 'dolls' when filled. Cover the container with wax paper or plastic material held in place with a rubber band and then place it in the refrigerator for the desired time.

When the low temperature period of incubation has been completed, move the container and 'dolls' to a warm room and read the germination three days later. The germinating seeds and seedlings are grouped into three categories: 'strong', 'weak', and 'dead'. Two 'weaks' are counted as one 'strong' in calculating the percentage germination."

Rolled towel cold tests have been used by Hoppe (1955) for testing fungicides, genetic resistance of inbred lines, adequacy of commercial seed treatments, and demonstrating the inferior qualities of old seed.

Meyers (1924) reported on the relation between pericarp injury and germination of maize. He found that broken pericarp resulted in reduced field stands when the soil was cold and wet. He also reported that inoculation with a spore suspension of *Penicillium* sp. reduced the germination of samples with pericarp injury more than samples without injury. Koehler (1936) also found that seed coat injury affected germination, vigor, and yield of maize.

A. *Sound check*
B. *Severe crown injury*
C. *Slight crown injury*
D. *Tip cap broken off*
E. *Injury at back or side of kernel*
F. *Injury over plumule*
G. *Injury over radicle*
H. *Injury at edge of germ*

FIGURE 50. - *Note the difference in stand and vigor of these maize seedlings grown from seed with different types of seed-coat injuries. The seed was planted in soil taken from a field, kept at 50°F. for two weeks, then allowed to grow at 70°F. in a greenhouse.*

(Courtesy, B. Koehler)

The effect of seed coat injury on seedling blight was reported by Koehler in the *Illinois Agricultural Experiment Station Report for 1938-47* (1948). He found that seed coat injury was caused primarily by mechanical harvesting and processing. Injuries caused by corn ear-worms, field mice, and growth checks were of less importance. Differences in stand and vigor of seedlings grown from seed with different types of seed-coat injury are shown in Figure 50. Treatment with appropriate seed disinfectants gave considerable protection against seedling blight when the seed coats had been injured. The nonmercurial compounds, Arasan and Spergon, gave better protection than the mercurial compounds, Semesan Jr. and Barbak. The best seed treatment, however, was inferior to sound seed.

Tatum and Zuber (1943) reported a close relation between inconspicuous pericarp injury over the germ, and stand and yield in the field. The seriousness of a break depended upon how direct an opening it provided for pathogens to reach the embryo. Pericarp injury was increased by shelling, elevating, dropping and grading the seed during processing. They found that the damage was cumulative. Low moisture content of the seed during shelling and other processing operations greatly increased

the amount of injury. Fungicidal dust treatment was not an adequate means of preventing poor stands in the field.

Kaewer (1954) also found that seed coat injury was increased by mechanical shelling. For example, 14 percent of the seed coat was damaged by hand shelling, but such damage increased to 47 percent by using mechanical shellers with steel paddles and operated at 290 rpm. Rough treatment during processing lowered seedling vigor. Ability of seed to withstand adverse spring conditions was affected by the moisture content of the seed at harvest, and field and climatic conditions during the next growing season.

Helgason (1953) presented evidence that the cold tolerance shown by seed from the F_1 single cross was closely related to the average tolerance of the parental inbreds. Two cold-tolerant inbreds usually produce a more cold-tolerant single cross than one tolerant and one susceptible inbred. The manner of combining the parental inbreds of a double cross is affected by combining ability, yield, and maturity of the inbreds; and yield and maturity of the single crosses. Within the limits of these restrictions, it usually is best to include the two most cold-tolerant inbreds in the seed parent single cross.

Rinke (1954) in a review of experimental cold testing, pointed out that inbreds A21 and A34 are high germinating in a cold test while A95 and A109 germinate poorly. The importance of the maternal parent is indicated by correlations:

1. single-cross stands vs. female parent $= + 0.67$;
2. single-cross stands vs. male parent $= + 0.14$;
3. double-cross stand vs. average of female inbreds $= + 0.69$;
4. double-cross stand vs. average of male inbreds $= + 0.26$.

A test of F_1 seedlings will probably give the reaction of the female inbred. A test of F_2 seedlings will be primarily a test of the F_1 parent, and a test of F_3 seedlings may primarily express the reaction of the F_2 genotypes.

Pinnell discussed breeding for cold tolerance in the 1954 report of the Seventh FAO Hybrid Maize Meeting. He listed genetic and environmental factors affecting germination at low temperatures (1949). He stated that the breeder needed to select genotypes having resistance to soil-inhabiting organisms which cause kernel rot and seedling blight at low soil temperatures. Pinnell stated that established inbred lines have been germinated in Minnesota at low temperatures in both laboratory and field tests. Interannualar correlations were $r = 0.4$ or 0.5. Testing open-pollinated seed of inbred lines harvested from replicated plots has been satisfactory. Inbreds may also be evaluated by testing open-pollinated seed harvested from all-combination single-cross trials. This method

minimizes the effect of maturity on the performance of the inbreds since single crosses mature earlier than their inbred parents. Some established inbreds are heterogeneous for cold tolerance and within-line selection is often effective in isolating sublines with greater cold tolerance.

The following conclusions based on trials and genetic theory were suggested by Pinnell in developing new cold tolerant inbreds:

1. Single ear tests will be most effective in generations with maximum genetic variance such as S_0 or S_1 populations from varieties or in F_1s from single crosses.
2. Single ear selection will become less effective as inbreds approach homozygosity.
3. The cold tolerance of a single ear can best be determined by testing seed harvested from the mature plant progeny of that ear.

He concluded that the genetic nature of resistance was complex because of environmental variation. The maternal parent is important in determining the cold tolerance of the cross. Variables affecting cold tolerance include environmental factors of mechanical damage to the seed, differential maturity, and frost damage.

Koehler (1954) studied conditions influencing the results from maize seed treatment tests. Factors affecting the condition of the seed included pericarp injuries, age, maturity, resistance to seedling blight, frost damage, and method of drying. Important environmental factors included the soil fungus flora, soil temperature, and soil moisture. Commercially processed seed had pericarp injuries in 81 percent of the kernels. A staining technique was required to find many of the broken places. Mature seed with sound pericarps did not respond to seed treatment in stand or yield.

Kaewer (1954) reported on maturity in relation to seedling vigor. He studied the effect of certain processing steps on seedling vigor and the responses which can be attributed to the maturation process during the final days in the production field and before harvest. His data were based on results obtained from a cold test designed to simulate cold, wet, adverse spring field conditions. Processing damage begins when a mechanical picker harvests the crop. Improperly adjusted snapping rolls, husking beds and husking pegs cause damage. Inclusion of rubber areas in the husking beds and removal of pegs reduced the damage.

Resistance to Chemical Weed Sprays

Increased use of chemical weed sprays has promoted maize production in many countries but has also caused some problems. Herbicides injure some varieties under certain developmental or climatic conditions.

Spraying to control weeds began soon after the discovery that 2,4-D (2,4-dichlorophenoxyacetic acid) would kill most broadleaved plants

but would not seriously injure members of the grass family. Slife (1954) estimated that over two million acres of maize were being treated annually with 2,4-D as a post-emergence spray in the Corn-Belt area of the United States.

Stringfield (1955) pointed out that.

"The purpose of the pre-emergence spray is to kill both annual grasses and broadleaved weeds as they germinate or soon after. It should be applied after the corn has germinated but before the first leaves have unrolled. Both the ester and amine formulations of 2,4-D are used for pre-emergence application, but the esters leach less rapidly and are, therefore, less hazardous to the corn. Recommended rates range from 1 to 2 pounds of acid equivalent per acre. The lower rates are used on the more porous soils.

Pre-emergence treatment is hazardous on sandy soils. It will be ineffective without enough rain to leach the 2,4-D into the zone of germinating weed seeds, and it may give poor control in cloddy soil. The surface soil should not be disturbed for two to three weeks after the application.

Early post-emergence sprays are applied overall when the corn is 3 to 12 inches high. The recommendations on an acre basis are ¼ pound acid equivalent for the esters of ½ pound for the amine salts. This treatment is in the experimental stage. Damage to the corn (maize) is always possible if cultivation or windstorms follow treatment, and the hazard increases as the corn gets larger or encounters high temperatures.

Post-emergence treatments may be applied with drop nozzles after the corn is 1 to 2 feet high, or tall enough so that the spray can be directed toward the base of the stalk and toward the upper parts of the weeds. This treatment is often highly effective against most broad-leaved weeds, and it can be recommended where earlier control methods have failed or could not be used. The recommended rates are the same as for early post-emergence treatment.

A 'lay-by' spray directed at the ground and stalk bases only, and after the final cultivation, may be worth-while on bottom lands. It will keep most annual weeds from becoming established for about three weeks. The esters of 2,4-D at 1 pound or the amine salts at 1 ½ pounds acid equivalent per acre are recommended.

At least 5 to 10 gallons of water per acre should be used with any of the treatments referred to above. Extreme care is required in calibrating the spraying equipment and in maintaining correct and constant driving speeds. Spraying with 2,4-D should not be attempted if there is enough wind to carry spray to susceptible crops in other fields. Spraying should be avoided after a period of hot, moist, favorable growing weather. Cultivation is not desirable for at least a week to 10 days after spraying."

Lee (1952) stated that some injury could be expected from use of 2,4-D on maize when temperatures and moisture conditions were favorable for rapid growth. Symptoms of injury include temporary lodging, plant brittleness, malformation of brace roots, and rolling of leaves. Yields may or may not be affected, depending on the severity of damage and the ability of plants to outgrow the effects of the chemical.

Genetic differences among inbred lines and hybrids may vary the degree to which maize is injured by 2,4-D sprays. Jugenheimer, Slife and Fuelleman (1948) reported that spraying inbred lines with 2,4-D

solution during flowering caused extreme differences in lodging (Table I, in the Appendix). The material included 145 inbred lines from 15 states and the United States Department of Agriculture. Most of these lines are widely used in the Corn Belt.

The plants were sprayed with ½ pound of amine acid in 100 gallons of water per acre when most of the lines were tasseling. Ten days after spraying the plants were graded for lodging. The amount of lodging was reported in five grades:

1. no lodging;
2. light lodging;
3. average lodging;
4. more than average lodging;
5. very heavy lodging.

The percentage distribution of the lines was as follows:

Grade	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Percent of lines	0	3.5	4.5	7.5	10.5	24.5	28.5	13.5	7.5

A difference of 1.5 between any two lines was significant at the 1 percent level. The following lines graded 2.0 or less and were most resistant to lodging: A111, A116, A158, A12, A340, A334, Os420, I11. Hy2, K63, Kys, K201C, B10, and CI.21E. The following lines graded 5.0 and lodged badly: A7, Os426, L289, Ind. H5, Mo.2RF, Iowa 159, Ind. 33-16, Ky. 39, Ky. 58, CI.187-2, K148 and CI.5.

Leng and Slife (1948) reported that seedlings of inbred lines differed in their response to 2,4-D treatment. Anderson and Wolf (1948) also found that inbred lines and hybrids differed in percentage of affected seedlings when 2,4-D was applied to the soil in pre-emergence treatments. Rossman and Staniforth (1949) stated that inbred lines M14 and W22 were more susceptible than Os420 to rolling of leaves, inhibition of brace root development, and defective tassel formation when 2,4-D was applied to the foliage at the six- to eight-leaf stage.

Mechanical Harvesting

Mechanized harvesting of the maize crop has been greatly stimulated in the United States by the use of desirable hybrids with superior standability and by the shortage and high cost of labor. More than 90 percent of the crop in the Corn Belt is now harvested mechanically from standing stalks. Therefore harvestability with a mechanical picker is an important character that should be bred into new hybrids. It includes such factors as the time required to harvest, ear droppage, ears left on

FIGURE 51. - *Harvestability of hybrids may be evaluated on small plots by use of a two-row picker mounted on the tractor.*

plants, husks left on harvested ears, and shelled corn lost on the ground (Jugenheimer, 1949).

The performance of new experimental hybrids is usually determined by comparing them side by side in small plots that are two rows wide by five or ten hills long. These plots are usually harvested by hand. This procedure gives little information on the harvestability of the hybrids by machine. Information on harvestability is therefore usually not obtained until the hybrid is grown by farmers on a field scale. Consequently, hybrids that are not suitable for machine harvesting have been released in the past by maize breeders for commercial use.

Experiments conducted at the Illinois Agricultural Experiment Station since 1947 by Jugenheimer (1949) and Jugenheimer *et al* (1949a, 1949b, 1954) proved that harvestability of inbred lines and hybrids may be evaluated on plots no larger than those commonly used for hand-harvested performance tests. The only change needed to adapt them to machine harvesting is to separate the different strains on the ends of the plots by 10-foot alleys. This space may be left vacant or planted. If it is planted, the border hills can be harvested with a mounted picker before the regular plots. Tests have included hundreds of inbred lines and hybrids. A picker mounted on the tractor can harvest two rows without affecting adjacent plots (Figure 51).

FIGURE 52. - *Hybrids with heavy lodging, excessive leaves, and large plants (above) require more power, cause clogging, and contribute to greater field losses than hybrids that are better adapted to machine harvesting (below).*

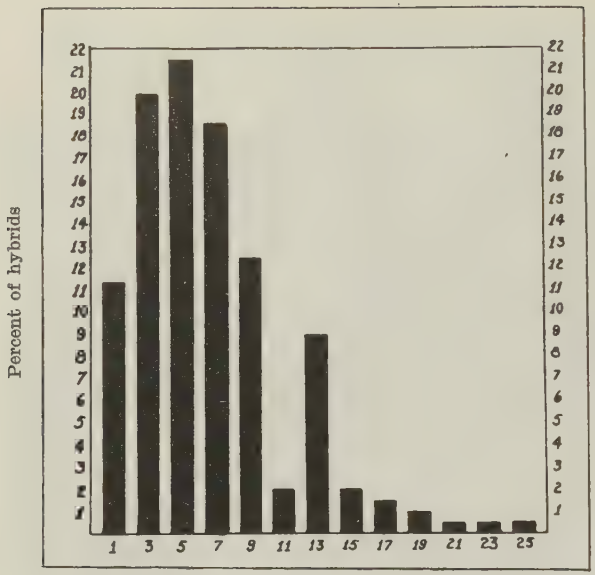


FIGURE 53. - *Heavy stalk rot infection, corn borer infestation and strong winds caused ear droppage of 196 hybrids to range from 0 to 2,533 per acre in Urbana, Illinois, in 1949.*

(Courtesy, R. W. Jugenheimer)

Objectives of the Illinois studies were:

1. To find inbred lines and hybrids that are better adapted to machine harvesting;
2. To study the factors responsible for the differences between them.

Maize inbreds and hybrids differed greatly in:

1. *Time and power required to harvest.* Heavy lodging, excessive leaves, and large plants contributed to loss of time and power. (Figure 52).
2. *Ear droppage.* Mechanical harvesters cannot pick up ears that have fallen to the ground. Such ears are lost unless the field is gleaned. Ear droppage of individual hybrids in 1949 ranged from 0 to 20 percent of the total yield (Figure 53). Differences in disease and insect resistance and length and strength of shank were important contributing factors.
3. *Ears left on plants by harvester.* Under conditions of heavy lodging, a correlation of + .8 was obtained between percentage of ears left on the plants and percentage of lodged plants. In comparable tests in 1947, K180 single crosses averaged only 13 percent erect at harvest (Table 15) while CI.7 crosses averaged 60 percent erect. Over 19 percent of the ears of all the K180 single crosses were left in the field by the mechanical harvester compared with only 4 percent of the ears of the CI.7 crosses (Table 16).

TABLE 15. — AVERAGE PERCENTAGE OF PLANTS ERECT AT HARVEST OF LATE YELLOW SINGLE CROSSES, URBANA, ILLINOIS, 1947

Parent lines	U.S. Cl.7	Ind. H7	ILL. R38	Kans. K148	Kans. K180	Mo. 940	ILL. Hy2
Cl. 7	—	63	43	82	44	66	62
H7	63	—	64	74	7	36	59
R38	43	64	—	1	1	2	40
K148	82	74	1	—	16	48	62
K180	44	7	1	16	—	6	3
Mo. 940	66	36	2	48	6	—	62
Hy2	62	59	40	62	3	62	—
Mean	60	50	25	47	13	37	48

NOTE: A difference of 40 percent between any two entries is significant at the 5 percent level.

SOURCE: Jugenheimer, unpublished.

TABLE 16. — AVERAGE PERCENTAGE OF EARS LEFT BY HARVESTER ON PLANTS OF LATE YELLOW SINGLE CROSSES, URBANA, ILLINOIS, 1947

Parent lines	U.S. Cl.7	Ind. H7	ILL. R38	Kans. K148	Kans. K180	Mo. 940	ILL. Hy2
Cl. 7	—	3	1	0	12	8	2
H7	3	—	2	0	9	7	11
R38	1	2	—	11	20	20	8
K148	0	0	11	—	18	5	1
K180	12	9	20	18	—	31	24
Mo. 940	8	7	20	5	31	—	9
Hy2	2	11	8	1	24	9	—
Mean	4	5	10	6	19	13	9

NOTE: A difference of 17 percent between any two entries is significant at the 5 percent level.

SOURCE: Jugenheimer, unpublished.

4. Husks left on harvested ears. For individual hybrids, husks left on the harvested ears ranged from 0 to 10 grams (Table 17). K180 crosses averaged 2 grams of husks per ear compared with 6 grams per ear for K148 crosses. Hybrids differed in amount, length, and tightness of husks.

5. Shelled grain lost on ground. In general, the earlier maturing hybrids with low moisture in the grain shelled easier than strains with higher moisture contents. All of the above harvestability traits appear to be conditioned by genetic factors.

TABLE 17. — AVERAGE GRAMS OF HUSKS LEFT ON EACH HARVESTED EAR OF LATE YELLOW SINGLE CROSSES, URBANA, ILLINOIS, 1947

Parent lines	U.S. Cl.7	Ind. H7	Ill. R38	Kans. K148	Kans. K180	Mo. 940	Ill. Hy2
Cl. 7	—	4	6	6	2	4	4
H7	4	—	9	5	0	2	2
R38	6	9	—	9	2	2	3
K148	6	5	9	—	4	10	4
K180	2	0	2	4	—	0	1
Mo. 940	4	2	2	10	0	—	3
Hy2	4	2	3	4	1	3	—
Mean	4	4	5	6	2	4	3

NOTE: A difference of 4 grams between any two entries is significant at the 5 percent level.
SOURCE: Jugenheimer, unpublished.

Smith and Sorenson (1948) in Texas reported that machine efficiency decreased with increased lodging, dryness, and brittleness of the stalks.

Smith, Lyness, and Kiesselbach (1949) in Nebraska reported a mechanical picker loss of 15.2 percent for U.S. 13 compared with only 3.2 percent for Kansas 2234. They also found that shellage losses of Ohio C92 were inversely related to moisture content of the grain. Losses ranged from 2.0 percent for grain with 21.7 percent moisture to 14.7 percent loss for grain with 14.7 percent.

In maize yielding 80 bushels an acre, Bateman, Pickard, and Bowers (1952) in Illinois reported a loss of 1.33 bushels per acre for each $^1/_8$ inch increase between snapping rolls beyond that required to prevent clogging. Increased speed from first tractor gear to second gear increased picker loss 2.7 bushels per acre.

Woods and Rossman (1955) studied three hybrids ranging from 90 to 110 days in maturity, averaging 10,300, 14,865, 18,890, and 22,900 plants per acre, and grown at six locations in Michigan. Total mechanical picker losses ranged from 6.0, 6.9, 10.3, and 13.4 percent of the total yield for the four plant populations, respectively. Stalk lodging increased with an increase in plant population.

King, Peterson and Curley (1955) in California found that ground speed and snapping roll adjustment were the most important factors determining picker losses.

Harvesting the maize crop in the future will probably involve greatly increased use of field shellers, modified combine harvesters, and artificial drying. The solution of mutual problems will require the co-operation of agricultural engineers and plant breeders.

COMPOSITION OF PLANT AND EAR

Maize is extremely variable. Consequently, breeders are able to select plants and ears suitable for particular uses. Workers may choose between dent, flint, sweet, pop, waxy or floury maize. These types, however, may be modified greatly by breeding and selection.

Livestock Feed

From 75 to 90 percent of the maize crop in the United States is fed to livestock. In contrast, most of the maize crop is used for human food in some areas of the world. Increased yields in these countries from the use of adapted hybrids and modern production practices could make vast quantities of maize available for livestock feeding. Most livestock feeders in the United States prefer a grain which is yellow in color, soft in texture, and high in quality and quantity of protein. Feeders in many other countries prefer a white maize.

Maize has certain limitations for feeding. It is primarily a source of energy, but is low in quantity and quality of protein and is relatively low in vitamins. Some feeders complain of poor palatability and reduced gains from hybrids compared with open-pollinated varieties. Many feeders grind flint maize and the harder dent types. Most feeding tests, however, have shown that hybrid maize is as satisfactory for feeding purposes as open-pollinated varieties.

High tonnage and excellent quality of silage and green feed need consideration. Bachman has evaluated maize for silage (*Report of the Fifth FAO Hybrid Maize Meeting, Zurich, Switzerland, 1952*). He pointed out that maize for silage should be cut at the early dough to late milk stage, corresponding to a 25 to 30 percent dry matter content, and that varieties which reached this stage of maturity at the appropriate harvesting time should be grown. Silage should be evaluated on the following criteria:

1. yield of dry matter;
2. percentage of dry matter;
3. proportion of ears to stalks and leaves;
4. percentage of crude fiber and protein.

If possible, these evaluations should be supported by digestibility experiments, feeding trials, and investigations of losses in conservation.

A number of workers in Europe and the Mediterranean countries have conducted research on maize for silage and green feed. Summaries of some of this work were compiled by Jugenheimer and Silow (1953, 1954).

Milling Industry

Three major industrial users of maize are the wet millers, dry millers, and alcohol producers. These industries prefer maize with certain characteristics which, in turn, require the consideration of the plant breeder.

Wagner (1947) pointed out that the wet miller desires maize with four characteristics:

1. freedom from non-maize materials;
2. low moisture content;
3. sound physical condition;
4. high percentages of starch, oil and protein.

High moisture grain packs in cars, which makes it difficult to unload. High moisture content also necessitates the handling of more total bushels in order to maintain the standard output of finished materials. It also interferes with the water balance in the milling system.

Damaged maize increases greatly the problems involved in unloading, cleaning, and storage operations. The greatest loss in processing damaged maize is that of oil, the most valuable constituent. Some types of damage cause modification and solubilization of the starch; others cause changes in the starch and protein which prevent proper separation in the milling process.

Three corrective measures are necessary:

1. growing maize of sufficiently early maturity to insure maturation before frost;
2. permitting the crop to stand in the field to dry naturally;
3. cribbing it under proper conditions for drying.

Millers desire strains which are high in starch, oil, and protein. Since maize contains around 70 percent (dry basis) starch, a variation of 1 or 2 percent is important in large-scale operations. The industry claims that flinty types do not steep and process as well as softer types.

Martin (1947) discussed quality in the dry milling industry. An adequate supply of white maize is another requirement of dry millers. Consumers claim a distinct preference for flavor and taste of meal made

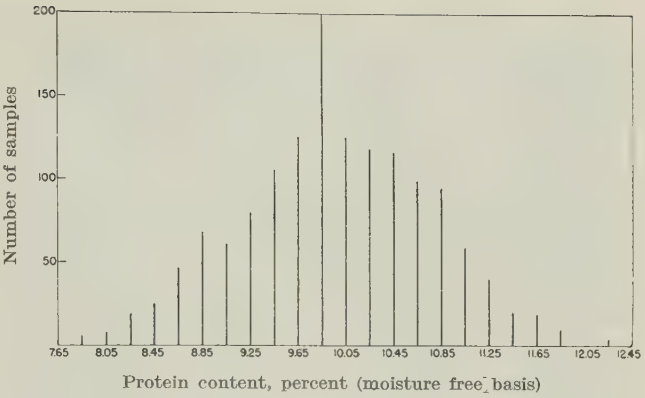


FIGURE 54. - *Protein content of 579 different maize hybrids in Illinois performances tests ranged from 7.85 to 12.45 (percent.)*

(Analyses by the Northern Regional Research Laboratory, Peoria, Illinois)

from white maize. The miller does not want maize of mixed colors. The finished product demand is for true colors, either pure white or pure yellow.

Dry millers also require a raw product in sound physical condition, containing less than 15 percent moisture, and with not over 8 percent of small kernels. Light-weight kernels, below 50-pound test weight per bushel, are objectionable because modern cleaning equipment results in considerable loss. A small kernel is especially objectionable to the miller who mills for large hominy grits and high oil yield.

A black or brown speck on the end of the germ is very objectionable and hard to remove. Many consumers believe that this black speck is contamination. Apparently it is possible to produce strains free of these objectionable specks by breeding.

Most dry millers prefer a kernel of semihard, vitreous or clean starch type, and which does not have too much soft starch on either the tip or the dent end. They do not want the shoe-peg type, nor the small, round kernels. The dent must not be too deep or the hull too rough. Kernels of this type make chaffy or chalky products which are only fit to put in feed. The cob color is of little consequence.

Protein Content and Quality

Protein content of 579 different hybrids in Illinois performance tests ranged from 7.85 to 12.45 percent with a mean of 9.96 percent (Figure 54). These tests were grown on fields of better than average fertility. Hunter (1947) stated that the protein content of maize in the United States had gone down from 9.5 percent or higher to 8.5 percent or lower within ten years. He also pointed out that it would take 2¼ million tons of soybean meal or its equivalent to bring the feeding portion of the 1946 U.S. maize crop up to 9.5 percent protein. He believed that this dwindling protein percentage meant a severe economic loss to the country.

FIGURE 55. - *Selection for composition by appearance is effective. High protein strains tend to have smaller kernels with more horny endosperm than low protein strains. Since most of the oils is in the germ, selection for high oil has resulted in a smaller kernel with a larger germ than for low oil.*

(Courtesy, C. M. Woodworth and R. W. Jugenheimer, 1949)

A. *High protein*
B. *Low protein*
C. *High oil*
D. *Low oil*

Illinois maize yields from 1946 through 1955, when hybrids were grown on most of the maize acreage, averaged 59.4 percent, or 20 bushels an acre above the average yield of the 71 previous years of open-pollinated varieties. Despite the fact that the percentage of protein may have dropped from 9.5 percent to 8.5 percent, many more pounds of nitrogen were removed per acre by the hybrids than by the open-pollinated varieties. Consequently, an adequate nitrogen fertilization program must be associated with the efficient use of maize hybrids.

Protein is an expensive but necessary constituent of food and feed. The Illinois selection experiment, discussed in Chapter 6, gave the first evidence that the protein content in maize can be increased or lowered by breeding (Woodworth and Jugenheimer, 1948, and Woodworth, Leng, and Jugenheimer, 1952). After 50 generations of selection, the mean

protein content of Illinois High Protein was 19.5 percent and 4.9 percent for Illinois Low Protein (Figure 19, page 54). Unfortunately, these open-pollinated strains yield only about 50 percent as much grain as do adapted hybrids.

Hayes and Garber (1919) isolated two strains from Minnesota 13 that averaged 15.0 percent protein compared to 10.2 for the parent variety. East and Jones (1920) found that selfing reduced yield, size of ear, size of seed, and number of seeds per ear. Using a system of alternate selfing and crossing of strains, they obtained strains with increased protein content, considerable vigor, and fair grain yields. Hayes (1922) developed several inbred lines which ranged from 15 to 18 percent protein.

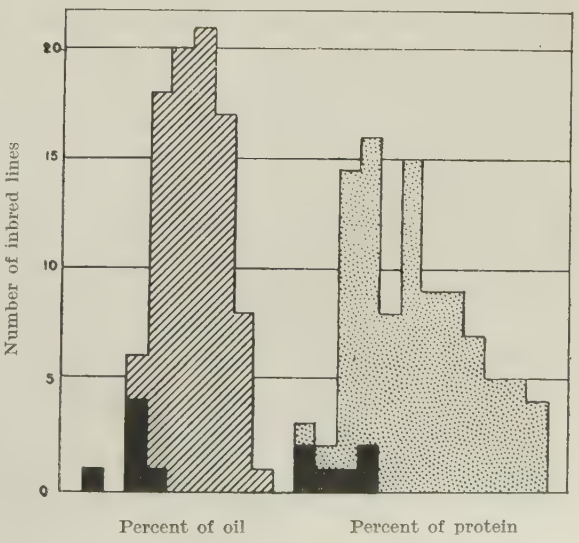
Woodworth and Jugenheimer (1949) reported on Illinois experiments to add high protein content to standard inbred lines desirable in other traits. Inbred lines Hy, WF9, 187-2, L317, 38-11, and A were crossed to the Illinois High Protein. Then the hybrids were backcrossed to both parents. After that, the backcrossed progenies were selfed for several years. During the selfing period, selection for high protein was carried on by selecting ears bearing hard, flinty kernels (Figure 55). Both yellow and white segregates were selected. Chemical analyses were not made until the beginning of tests for combining ability.

Practically all of the recovered lines were considerably higher in protein content than the standard lines. The protein content of these new lines ranged from 11 to 22 percent compared to a range of 11 to 14 percent for the original standard lines (Figure 56).

Furthermore, it was found that back crosses to the Illinois High Protein gave new lines with higher protein content than back crosses to

FIGURE 56. - *More oil and protein were added to standard inbred lines of maize by breeding. The new high-oil lines range from 4 to 10 percent oil, compared with 2 to 5 percent for the original lines. New high-protein lines range from 11 to 22 percent protein, compared with 11 to 14 percent originally.*

(Courtesy, Illinois Agricultural Experiment Station Report, 1947-48)



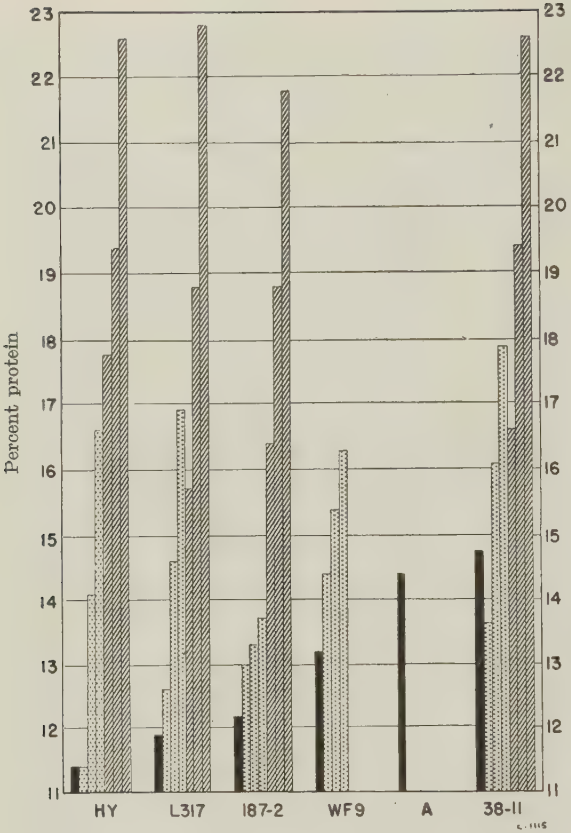


FIGURE 57. - *Back crosses to the Illinois High Protein strain gave new lines with much higher protein than back crosses to the standard inbreds.*

(Courtesy, C. W. Woodworth and R. W. Jugenheimer, 1949)

the standard inbreds. For example, new lines involving L317 analyzed as high as 16.9 percent protein when backcrosses were made with L317. However, similar material backcrossed to the high protein strain resulted in new lines that analyzed as high as 22.8 percent protein. This compares with 11.9 percent for the original L317 (Figure 57).

Several experimental double-cross hybrids involving these recovered inbred lines have averaged considerably higher in protein and oil content and were even slightly superior to standard hybrids in grain yield and standability (Table 18).

Grain of 145 standard inbred lines ranged in protein percentage from 9.7 to 16.1 with an average of 12.3 (Table V in the Appendix). Protein content was significantly correlated with maturity, plant and ear height, stalk lodging, grain yield, and certain diseases and insects (Table 10, page 100).

Quality of protein is fully as important as quantity of protein. The maize kernel contains two main types of protein. That found in the endosperm is primarily zein. Zein is deficient in tryptophan and lysine, which are essential for animal nutrition. The other type, found in both

TABLE 18. — COMPARISON OF ILLINOIS HIGH-PROTEIN AND ILLINOIS LOW-PROTEIN OPEN-POLLINATED STRAINS OF MAIZE WITH HIGH-OIL HYBRIDS AND U.S. 13, URBANA, ILLINOIS, 1951

Strain or hybrid	Yield, bushels per acre	Oil content		Protein content	
		Percent	Lbs. per acre	Percent	Lbs. per acre
U.S. 13	117	5.06	332	9.69	635
ILL. High Oil	55	12.84	394	11.56	355
ILL. High Protein	51	5.42	155	19.32	551
ILL. 6063	127	6.22	441	10.22	724
ILL. 6016	118	6.66	441	10.16	673
ILL. 6021	117	6.55	429	10.91	714
L.S.D.	7	0.36	—	0.58	—

SOURCE: Jugenheimer, unpublished.

endosperm and germ, contains both tryptophan and lysine and is biologically balanced. The maize breeder would like to increase the percentage of these amino acids in the endosperm protein. The alternative is the addition of these amino acids to the diet from other sources.

Dobbins, Krider, Hamilton, and Terrill (1950) concluded that the protein of low-protein maize had a higher biological value than high protein strains. Hamilton, Hamilton, Johnson, and Mitchell (1951) reported that kernels of maize grown on soils of low fertility were 26 percent smaller than from fertilized plots, and the germ occupied 17 percent less of the kernel. Grain on the unfertilized plots were below normal in phosphorus, oil and protein.

In general, high protein types tend to be hard and flinty, which trait is not popular with livestock feeders. The wet milling industry maintains that flinty types of maize do not steep and process as well as do the softer types.

All available evidence indicates that protein content is a quantitative character with a complex mode of inheritance typical of such characters. East and Jones (1920) stated that protein content is due to a large number of inherited factors, that various strains having the same content probably differ in such factors, and that there is a chance of obtaining still higher percentages by crossing them. Dominance relationships and protein percentage may be confounded by hybrid vigor.

Frey (1949) reported that protein, zein, tryptophan, valine, leucine, and isoleucine were determined by 22, 6, 15, 8, 8 and 6 genes respectively. He concluded that " the general nature of the interaction of genes determin-

ing protein, zein, tryptophan, valine, leucine and isoleucine percentages was found to be arithmetic in the high × low protein cross ". Low protein, low zein, low valine and low isoleucine were found to be dominant traits.

In the maize kernel about 20 percent of the protein is in the embryo and 80 percent in the endosperm. The embryo is one half male and one half female, but the endosperm is one third male and two thirds female. F_1 kernels borne on the high protein plant are high in protein content like the seed parent. F_1 kernels borne on the low protein parent are low like the seed parent. For example, Illinois High Protein seed parent × Illinois High Protein pollen parent gave 23.1 percent protein; Illinois Low Protein seed parent × Illinois High Protein pollen parent gave 10.9 percent protein. The male parent appears to have little or no immediate effect on protein content.

When F_1 seeds are planted and the F_1 plants grown and selfed, segregation for protein should take place on the ears borne by those plants. These are F_2 seeds. This segregation is not apparent when the kernels on the ear are analyzed together, as there is a composite or an average of the contents of many kernel classes. If individual kernels are not analyzed, some approximation to the actual results can be obtained by growing out a large F_2 progeny and selfing the individual F_2 plants. Ears borne on F_2 plants bear F_3 seeds. Each ear constitutes an F_3 family. Differences between F_3 families should approximate the segregation of F_2 seeds borne on F_1 plants.

The common assumption is that there is an inverse relationship between yield and protein content; i. e., yield declines as protein percentage increases. This assumption is supported by the correlation of -.522 between grain yield and protein content of 145 inbred lines (Table 10, page 100). The Illinois chemical strains have declined in yield, so that now they yield less than good open-pollinated varieties and still much less than good hybrids. This decline occurred in spite of the fact that all material has been crossed. Selfing has never been used. The material, however, was close-bred for more than 50 years. Selection has always been within the same material, since no new material has been brought in. Hence heterosis has declined, homozygosity approached, and yield factors lost. It is significant too that the high protein strain yields less than the low protein strain. This is not surprising when we observe that the ears and kernels of the high strain are smaller than those of the low strain (Figure 55, page 150).

Selection for protein in the Illinois chemical strains has been accompanied by changes in other characters as well as in yield. The high protein kernel has a hard, flinty endosperm, while the low protein kernel has a soft, opaque endosperm. Compared with the low protein ear, the

high protein ear is shorter, smaller in circumference, and has a slightly higher row number. Illinois High Protein shows much red color in the stalk, leaf sheath, and leaf. It has a stronger tendency to tiller than the low protein and is slightly earlier in silking. Height of stalk and ear are very nearly the same in the two strains.

Oil for Industry and High Energy Feed

Maize oil is a valuable by-product of the starch industry and is high in energy value for livestock feeding. Most of the oil is in the germ of the seed (Earle, Curtis, and Hubbard, 1946). Germ protein contains tryptophan and lysine, is biologically balanced, and is probably more valuable for livestock feeding than endosperm protein. High oil hybrids having a high proportion of germ to endosperm, therefore, should benefit both the starch industry and livestock feeders. Schneider, Early, and DeTurk (1952) also concluded that high oil maize had a higher biological value than low oil maize.

After fifty generations of selection at the University of Illinois, the mean oil content of Illinois High Oil was 15.4 percent compared to 1.0 percent for Illinois Low Oil (Figure 19, page 57). Unfortunately, these open-pollinated high oil strains are low yielding. The oil content of 579 differrent hybrids in Illinois Performance Tests ranged from 2.9 to 6.1 percent with a mean of 4.6 percent (Figure 58).

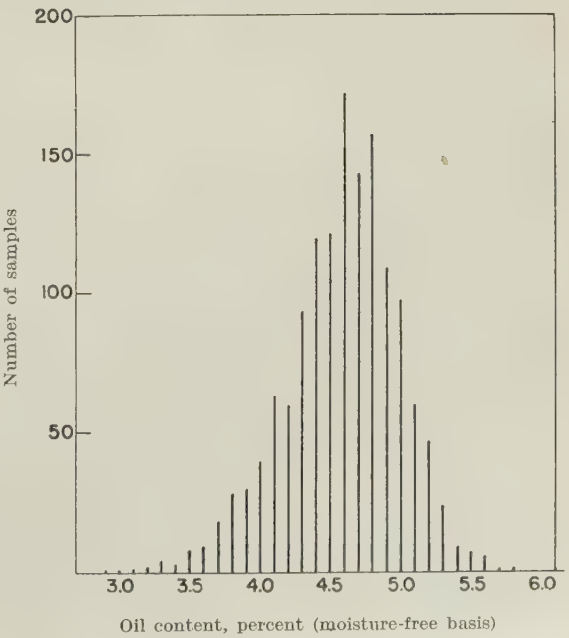


FIGURE 58. - *Oil content of 579 different maize hybrids in Illinois performance tests ranged from 2.9 to 6.1 percent.*

(Analyses by the Analytical Section, Northern Regional Research Laboratory, Peoria, Illinois)

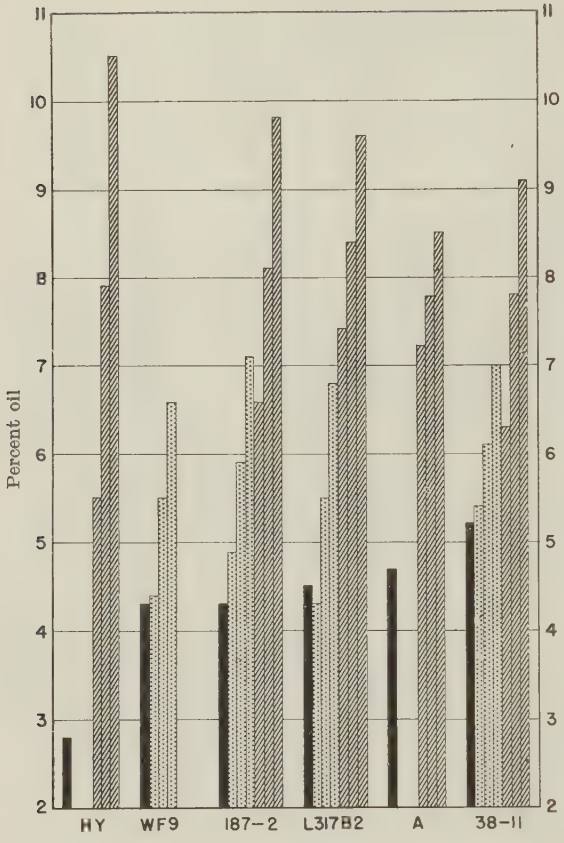


FIGURE 59. - *Inbred Hy was changed from 2.8 percent oil to 10.6 percent oil by backcrossing it to Illinois High Oil. Back crosses to the original lines resulted in lower oil content than when back crosses were made to the Illinois High Oil.*

(Courtesy, C. W. Woodworth and R. W. Jugenheimer, 1949)

High oil was transferred to standard inbred lines at the Illinois Station by backcrossing, selection, and self-fertilization. Selection for high oil was accomplished by selecting ears bearing kernels with large germs (Figure 55, page 150). Oil content of the new inbreds ranged from four to ten percent compared with 2 to 5 percent for the originals (Figure 56, page 151). Hybrids between Illinois High Oil and standard inbred lines were backcrossed to both parents. Back crosses to Illinois High Oil strains resulted in higher composition than back crosses made to the original inbreds (Figure 59).

Rather extensive programs have been inaugurated in Illinois, Iowa, and Indiana to develop inbred lines with high oil content by self-fertilization and selection. Sprague (1950) reported that the recurrent procedure, at the end of a five-year period, was 2.6 times more efficient than selection during inbreeding. Apparently grain yields received little or no consideration in this experiment.

Ill. 6063, an Illinois experimental double-cross hybrid developed by Jugenheimer, produced 14.0 percent more protein, 32.8 percent more oil, and was 8.5 percent superior to U.S. 13, a standard hybrid in grain yield (Table 18). Expression of high oil content does not appear to be influenced as much by environment as does high protein content.

" Student " (1934) calculated that at least 20 to 40 genes, and possibly 200 to 400 genes, are involved in the inheritance of high oil content. Sprague and Brimball (1949) reported that two crosses showed partial dominance of low oil content, a third was intermediate, and a fourth cross exhibited some evidence for dominance of high oil percentage. They concluded that both arithmetic and geometric gene action was involved.

Zein for Special Fabrics

Protein content of maize grain may be increased by breeding and by high applications of nitrogen fertilizers. Most of the increase of endosperm protein, however, is zein, which is distinguished from other maize proteins by being soluble in alcohol. Zein is not of high nutritive value because of poor balance among its constituent amino acids.

Zein is obtained from the gluten in the maize wet-milling process. The Northern Utilization Research Branch of the United States Department of Agriculture, Peoria, Illinois, studied the dispersion of zein in strong alkali, its " spinning " into a fiber, and the stretching and curing of this fiber to give added strength (Milner, 1954). It was found that fibers formed by forcing a viscous zein solution into an acid bath through a rayon-type spinnerette can be toughened, stretched, and treated with formaldehyde and acetic acid to give a satisfactory protein fiber. This fiber is available on the market under the trade name " Vicara " and is used mostly in blends with wool for such garments as socks, swimming suits, and sweaters. The increased use of zein for special fabrics has created some interest in breeding maize for higher zein content.

Waxy Maize for Amylopectin

Waxy maize refers to the waxlike appearance of the endosperm of the grain when it is cut or broken. It does not indicate the presence of true wax. Apparently, Reverend J. M. W. Farnham, a Presbyterian missionary in China, sent the first sample of waxy maize to the United States in 1908. The gene, wx, was named waxy by Collins (1909). Although China was the original source of waxy maize, waxy mutations have since occurred in American dent strains.

Waxy ears appear to be somewhat more starchy than ordinary maize. Staining, however, is the best way of distinguishing between dent and waxy types. Ordinary cornstarch stains blue with iodine solution, whereas waxy cornstarch stains a reddish brown. The waxy gene also expresses itself in the pollen, which is an aid in breeding (Longley, 1924).

Common corn starch is approximately 72 percent amylopectin and 28 percent amylose. Waxy starch is composed entirely of amylopectins

which is the branched molecular form. This difference in properties permits waxy starch to be used for products normally requiring tapioca starch.

Brink and Abegg (1926) reported that the starch from waxy maize was different from that found in ordinary maize. Brimhall and Hixon (1939, 1942), and Morgan (1940) found that the two types of starch have quite different pasting properties. Hixon and Sprague (1942) interpreted these differences in terms of molecular structure.

The waxy locus has several alleles. These are Wx, wx^a, and wx. Normal starch (Wx) is dominant to the other two alleles as measured by iodine coloration or the percentage of amylose.

Sprague *et al* (1943) have shown that gene action of the Wx allele appears to be additive on the basis of viscosity and rigidity measurements of the starch pastes (Table 19), and largely dominant with respect to its effect on the percentage of amylose.

TABLE 19. — GENE ACTION OF THE Wx ALLELE APPEARS TO BE ADDITIVE ON THE BASIS OF VISCOSITY AND RIGIDITY MEASUREMENTS

	Genotype of endosperm	Rigidity	Viscosity
Ia 939 sib-pollinated	Wx Wx Wx (dent)	222	24
Ia 939 ♀ x Waxy 939 ♂	Wx Wx wx	185	42
Waxy 939 ♀ x Iowa 939 ♂	wx wx Wx	61	67
Way 939 sib-pollinated	wx wx wx	0	490

SOURCE: Sprague *et al*, 1943.

Waxy inbred lines can be obtained by watching for waxy mutations on ears of dent inbred lines (Bear, 1944), or by adding the waxy gene to standard inbred lines having other desirable agronomic characteristics, by out-crossing, backcrossing, selfing, and selection. Double-cross hybrids of waxy maize have been developed and are now being grown commercially to produce a starch similar to tapioca starch.

The production of waxy maize creates some problems. Some of the waxy hybrids produce slightly lower grain yields and have greater stalk and root lodging than the better dent hybrids. Since waxy maize is a recessive characteristic, production must be isolated from dent maize to prevent losing the peculiar starch properties of the waxy. Care must be taken to prevent mixing of waxy and ordinary maize in harvesting, storing, etc. Other sources of waxy starch are sorghum, barley, rice, and millet.

Amylose for Plastics, Cellophane and Films

Amylose is a linear-type molecule which can be made into thin, transparent films which resemble cellophane. Acceptable films require amylose of about 80 percent purity. Ordinary maize contains about 27 percent amylose. Most reports of high amylose starch in maize have referred to the sweet type involving the genes su, su^{ma}, and du, in which the starch content is probably too low for commercial use at the present time (Cameron, 1947, Kramer and Whistler, 1949; Dvonch, Kramer and Whistler, 1951; and Dunn, Kramer, and Whistler, 1953).

Kramer, Whistler and Anderson (1956) reported a gene with slight morphological effects in normal dent endosperm, which increases amylose content to about 60 percent without increasing water soluble polysaccharides. The gene, ha (named "ae" by Bear), resides on chromosome 5, and is inherited as a simple recessive.

At the Northern Utilization Research Branch, United States Department of Agriculture, Peoria, Illinois, M. M. MacMasters and associates have analyzed many samples of maize in an effort to find strains with a high amylose content. Samples have been found in which the starch was 82 percent amylose. Consequently, it appears that it may be possible eventually to obtain dent maize with an amylose content which is high enough for the practical production of plastics, cellophane and films.

B-Carotene (Vitamin A)

Hauge and Trost (1930) reported an association in maize between yellow endosperm and vitamin A. Mangelsdorf and Fraps (1931) found a direct quantitative relation between vitamin A and the number of genes for yellow pigment in the endosperm. The triploid nature of the endosperm makes it possible to produce four classes of seed differing in the proportion of dominant and recessive genes. The average results for two years were as follows:

Number of genes for yellow	*Factorial composition of endosperm*	*Units of vitamin A per gram*
0	y y y	0.25
1	y y Y	2.25
2	y Y Y	5.00
3	Y Y Y	7.50

Apparently the yellow endosperm genes acted in an arithmetic, cumulative manner, with each gene adding 2.5 units of vitamin A per gram of grain.

Nicotinic Acid (Niacin)

Adequate niacin eliminates certain malnutritional disturbances. Richey and Dawson (1948) reported wide differences in niacin concentration among varieties of maize. Inbred lines ranged from 13.9 to 53.3 micrograms per gram. Hybrids tended to be intermediate between their parents, with the seed parent generally exercising more influence than the pollen parent. Leng, Curtis, and Shekleton (1950) found that dent kernels were lowest, waxy kernels intermediate, and sugary kernels highest in niacin content.

Sugar

Workers at the Connecticut Station have shown that maize can produce and store large quantities of sugar in the juice of the stalk. Since inbred lines differ considerably in sugar content, these workers feel that maize is a potential commercial source of sugar. Hybrids involving high sugar inbreds might also have increased value for silage.

12. IMPROVEMENT OF SWEET CORN AND POPCORN

The improvement of sweet corn, popcorn, and waxy maize requires special consideration. The terms "sweet corn" and "popcorn" seem to be preferred to sweet maize and pop-maize.

Sweet Corn

Poole (1937) and Smith (1955) give excellent reviews of the improvement of sweet corn. This crop is used as a canning or frozen vegetable throughout most of the world and as a market or green garden vegetable in regions favoring its cultivation.

The main region of sweet corn production is the northern half of the United States and southern Canada. There are several reasons for this restricted distribution. The period during which sweet corn kernels remain sweet after picking is very short. Sugars are rapidly converted to starch at the higher temperatures farther south. The corn ear worm is less injurious to sweet corn in latitudes with low winter temperatures that prevent winter pupation of the larvae. Bacterial wilt, or Stewart's disease, is especially severe in the south. In general, sweet corn also is quite susceptible to drought and smut.

Florida and other southern states are rapidly becoming centers of market sweet corn production for northern consumption in the winter and spring. Smith (1955) gives three reasons for the remarkable growth in this industry:

1. the development of new hybrids adapted to culture in the south;
2. the availability and wide practical use of effective new insecticides and fungicides for the control of ear worm and the leaf blights;
3. the development of improved packing and shipping materials, equipment, and methods (Boswell, 1952).

The history of sweet corn was reviewed by Smith (1955). Apparently the origin of this crop dates back to 1779 (Erwin, 1934). Singleton (1944) stated that a Connecticut lawyer, Noyes Darling, crossed a very early yellow strain with a sweet type in 1836 by detasseling the yellow

variety. The first hybrid to be grown extensively was developed by D. F. Jones and released by the Connecticut Station in 1924. The most popular and widely grown sweet corn hybrid, Golden Cross Bantam, was developed by Glenn Smith (Smith, 1933). Popular present-day American hybrids are listed in Table 20.

TABLE 20. — POPULAR PRESENT-DAY AMERICAN SWEET CORN HYBRIDS

Variety	Originator	Pedigree	Kernel color	Ear length, inches	Kernel rows, number
	Early Types (60 to 74 Days to Harvest)				
Spancross	Conn. A.E.S.	C13 x C3	Yellow	6½	10-12
North Star	Joseph Harris Co.	Closed	Yellow	6½	8-12
Marcross	Conn. A.E.S.	C13 x C6	Yellow	7½	10-14
Seneca 60	Robson Seed Farm	Closed	Yellow	6½	10-12
	Early Midseason Types (75 to 80 Days to Harvest)				
Carmelcross	Conn. A.E.S.	P39 x C13	Yellow	7	12-14
Gold Rush	Corneli Seed Co.	Closed	Yellow	7	12-14
	Midseason Types (81 to 89 Days to Harvest)				
	Conn. A.E.S.	P39 x C23	Yellow	7½	12-16
Lincoln	Northrup King & Co.	Closed	Yellow	8	10-14
Golden Bounty	Ferry Morse Co.	Closed	Yellow	8	12-14
F M Cross	Purdue A.E.S.	P39 x P51	Yellow	8	12-14
Golden Cross Bantam	Iowa A.E.S.	P39 x 145	Yellow	8	12-14
Ioana	Robson Seed Farm	Closed	Yellow	9	12
Seneca Chief	Assoc. Seed Growers	Closed	Yellow	9	12-14
Erie	Michael Leonard Co.	Closed	Yellow	9½	16-18
Aristogold Bantam Evergreen	Ill. A.E.S.	101q x 73c	Yellow	7½	12-14
Illinois Golden No. 10	F.H. Woodruff & Son	Closed	Yellow	8	14-16
Golden Security	F.H. Woodruff & Son	Closed	Yellow	8	16
Victory Golden Iochief	Iowa A.E.S.	515 x 453	Yellow	9	16-18
	Large Late Types (90 Days or over to Harvest)				
Evergreen 14 x 11	Ill. A.E.S.	14 p 11	White	8	16-20
Country Gentleman 13	Ill. A.E.S.	27a x 18b	White	7½	Irreg.

SOURCE: Smith, 1955.

The genetic composition of a sweet corn kernel differs from dent maize in only one recessive gene. This gene prevents the conversion of some of the sugar into starch. The kernel has a translucent, horny appearance and is wrinkled when dry. The sugary gene, su, is the basis for a large production of sweet corn. Mangelsdorf (1947) reported duplicate genes that determine amylaceous-sugary endosperm. He discussed the possible use of these genes in sweet corn breeding. Andrew *et al* (1944) reported that sweet corn recessive for the waxy gene (su wx) was superior to sweet corn that was dominant at the waxy locus.

Lindstrom and Gerhardt (1927) studied the chemical composition of known endosperm genotypes from crosses of dent × sugary. As shown in Table 21, an increase of sugars and a decrease of starches for each additional su gene (expressed as " s " in the table) was obtained in the recom-

binations resulting from reciprocal F_1 matings, backcrosses, or F_2 generation.

Problems in sweet corn breeding are discussed in detail by Smith (1955). The general objectives of sweet corn breeders include

1. production of high yielding, uniform hybrids with good quality;
2. extension of the range of adaptation.

Extension southward requires the development of improved disease- and insect-resistant types. The production of sweet corn may be extended northward by the development of earlier maturing strains. Sweet corn is especially susceptible to such hazards as diseases, insects, and drought. Improvement of these characteristics is discussed in other chapters of this book.

TABLE 21. — CARBOHYDRATE PERCENTAGES IN PARENTAL, F_1, F_2 AND BACKCROSS GENOTYPES OF THE KERNEL

Cross type	Endosperm genotype	Total sugar	Dextrin	Starch	Carbohydrate index [1]
		..... Percent			
White dent (HF) [2]	SSS	2.3	1.9	56.6	0.07
Evergreen sweet (E) [3]	sss	4.9	24.5	27.9	1.01
F_1, H.F. x E.	SSs	2.7	2.1	53.6	.09
F_1, E. x H.F.	ssS	3.6	1.7	56.1	.09
$F_1 \times$ E.	SSs	1.8	1.6	57.5	.06
	sss	5.3	25.7	23.1	1.34
E. x F_1	ssS	2.2	2.2	55.8	.08
	sss	4.5	25.9	27.1	1.12
F_2	SSS	2.3	2.7	57.5	.09
	sss	5.3	29.1	21.6	1.59

[1] Ratio of total sugar plus dextrin to starch. — [2] H.F. = High fat strain. — [3] E. = Evergreen parent.
SOURCE: Lindstrom and Gerhardt, 1927.

Desirable types of sweet corn for canning or frozen food involve several important characteristics. These include deep kernels, yellow or white depending on local preference, efficient production, high quality, and extreme uniformity of plant and ear. This uniformity includes the texture and consistency of the grains and the shape and size of ears. Obviously, satisfactory yields and high quality also are necessary. The puncture test was developed to identify tender inbred lines. This test shows the pressure in grams per square centimeter required to penetrate the pericarp of the kernel.

Two methods of canning are "whole-kernel" and "cream-style". Whole-kernel canning requires kernels with 72 to 75 percent moisture, and uniform ears with tender pericarp and fine flavor. Moisture content of cream-style canning corn should be 68 to 72 percent. Tenderness and good flavor are important considerations in commercial and home freezing of sweet corn (Smith, 1955).

The market gardener requires hybrids with the same characteristics as canned or frozen sweet corn except that it is desirable to have types that are not uniform in maturity in order that the crop may be used during a longer period of time. Special consideration must be given to sweetness, pericarp tenderness, consistency or texture of the kernel contents, and maturity. Sweetness is not quite as important in the case of canned or frozen sweet corn, since sugar may be added in the canning or freezing process.

Most of the sweet corn in the United States at the present time is single-cross hybrid. Single crosses contribute uniformity in texture and consistency of grains. Desirable shape and size of ears have revolutionized machinery and methods of handling in the cannery. The even placing of ears on the stalks and uniformity of maturity have resulted in great economy of production.

Golden Cross Bantam, developed by Smith in 1927 at Purdue University, Lafayette, Indiana, U.S.A., has been the most popular and widely adapted sweet corn hybrid. Golden Cross Bantam is a cross between P39 x P51. Both of these inbred lines were developed from Golden Bantam variety. The popularity of the hybrid is due to its excellent yielding ability, canning qualities, uniformity, and resistance to bacterial wilt.

Popcorn

Popcorn is a relatively minor crop compared with dent or flint maize. The cultivation and use of popcorn is almost entirely restricted to the New World. Only about 0.2 percent of the total maize acreage of the United States is planted to popcorn. The commercial crop is produced primarily in twelve states: Iowa, Illinois, Indiana, Nebraska, Kansas, Missouri, Ohio, Texas, Kentucky, Michigan, California, and Oklahoma.

Popcorn is grown for two primary purposes. It is used for human consumption as freshly popped corn and as a basis for confections. It is grown for home use and for vendors in amusement parks and cinemas.

Brunson (1937, 1955), Eldredge and Lyerly (1943), Brunson and Smith (1945, 1948), and Smith and Brunson (1946) have published excellent reviews of the breeding and production of popcorn.

Popcorn open-pollinated varieties and hybrids differ considerably in their popping ability. The phenomenon of popping, however, is not

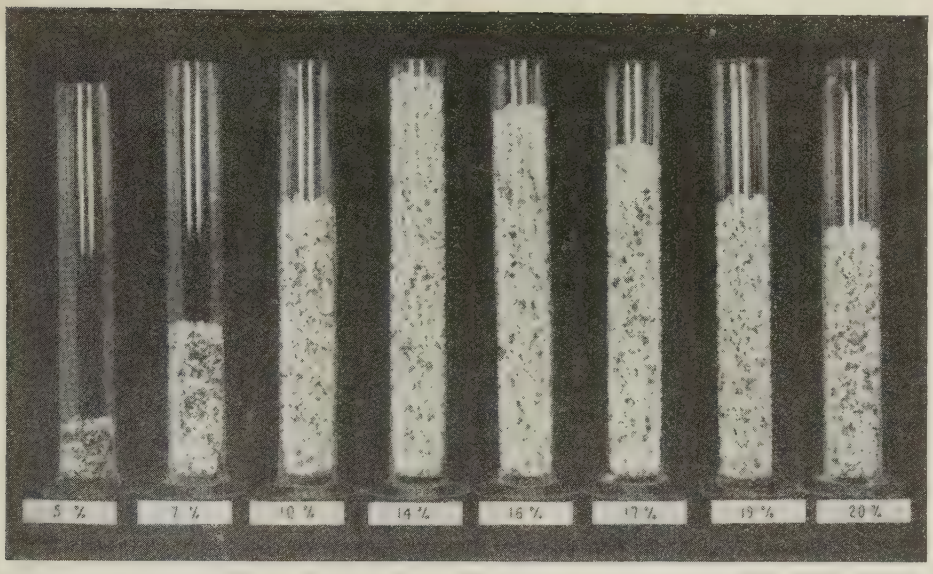


FIGURE 60. - *Moisture content of the popcorn kernel is an important factor in popping expansion. These cylinders give the comparative popping results from the same popcorn with different moisture percentages.*

(Courtesy, J. C. Eldredge, 1949)

limited to popcorn. Many flint types of maize pop fairly well, and even some of the horny dents pop a little. Some varieties of sorghum with seed of a dense, flinty structure, such as Pink Kafir, pop well. Manufacturers of breakfast cereals puff or pop wheat and rice to several times their original volume. They use mechanical methods of confining steam pressure within the grains until it is suddenly released.

Exactly why popcorn pops is not well understood. Weatherwax (1922) believed that the ability to pop is conditioned by the relative proportion of horny endosperm, where the starch grains are embedded in a tough, elastic, colloidal material, which confines and resists the steam pressure generated within the granule until it reaches explosive force.

Moisture content is an important factor in popping quality (Figure 60). About 14 percent moisture is optimum for best popping. Popping is due to the sudden release of pressure produced by steam generated within the kernel. The source of this steam is the moisture contained in the kernel. Popping properties seem to follow rather closely the relative proportion of horny starch.

The more important types and open-pollinated varieties of popcorn include White Rice, Jap Hulless, Queen Golden, South American, Spanish, and Supergold or Yellow Pearl. Jap Hulless is perhaps the oldest open-pollinated variety and has extremely high quality and popping expansion,

but low yields and poor standability. South American is a large-kerneled yellow pearl type with good yield and expansion. Supergold and Yellow Pearl are slightly earlier than South American. They are of the yellow pearl type with tapering ears, fairly small kernels, and excellent yields, quality and popping expansion.

The popcorn breeder must consider the interests of both the producer and consumer. The producers' interests include yield, standability, freedom from dropped ears, and resistance to hazards. High yields usually are cheap yields. Excellent standability aids in harvesting with a mechanical picker. Ears lying on the ground seriously affect quality. Susceptibility to diseases, insects, and drought reduces yield, affects quality, lowers popping expansion, and introduces off-flavors. Ear rots and stalk rots are important diseases, and European corn borer and corn earworm are important insects. The achievement of these desired characters in popcorn is similar to those for dent maize.

Important characters affecting the consumer include high popping expansion, tenderness, freedom from hulls, flavor, kernel shape, and color. Popping expansion refers to the volume of popped kernels obtained from a unit volume of unpopped kernels. It is usually expressed as the ratio of popped to unpopped grain. Popping expansion ranges from about 20 to over 30. Factors responsible for differences in expansion include methods of popping the grain, shape and size of containers, degree of packing the popped grain before reading the volume, differences in maturity, proper moisture percentage (13 to 14 percent), freezing before the grain is mature, rough handling or shelling, and the inheritance of genes conditioning a dense, elastic endosperm.

Unfortunately, there is a negative correlation between yield and popping expansion. However, it is possible to obtain extremely high-yielding hybrids with excellent expansion. Fortunately, tenderness accompanies high expansion. Tenderness includes the main portion of the popped kernel, and absence of a hard core at the base. Consumers desire a thin, tender hull which disintegrates in the mouth. They desire types with a sweet, pleasant flavor instead of a dent maize flavor. Kernel shape includes the mushroom type, which fluffs up to a distinctly globular form characteristic of South American strains, and the butterfly type, which turns inside out when it explodes. The color includes chalky white, cream colored, and a mottling of a deep yellow on the outside of the popped kernels.

Practically all of the commercial production of popcorn in the United States is now hybrid. Most of these hybrids are single crosses or three-way crosses. Popular hybrids have been developed by workers in Minnesota, Kansas, Indiana, and Iowa. Minhybrid 250 was the first hybrid to be grown commercially. Other Minhybrids include 251 and 252. However, these hybrids are limited by maturity to the northern edge of the

United States Corn Belt. Kansas hybrids 1, 2, 3, and 4 also are available. However, K4 is the most popular of these hybrids. Released Purdue hybrids include P20, P22, P31, P32 (same as K4), P38 and P202. Iopop hybrids 5, 6 and 7 also are available (Brunson 1955). Several hybrids developed by commercial seedsmen are also being grown.

Supergold, South American, and other open-pollinated varieties and inbred lines developed from these varieties exhibit an interesting cross sterility phenomenon. South American inbred lines, for example, will fertilize Supergold lines, but Supergold lines will not fertilize South American lines. Therefore, crosses involving these types can be made only in one direction.

Nelson (1952) found that cross sterility in popcorn was due to an allelic series Ga^s, Ga, ga located on chromosome four. Varieties may be classified into three groups. Brunson (1955) lists these as follows:

Cross sterile	*Neutral*	*Normal*
South American	White Rice	Supergold
Jap Hulless		Baby Golden - 1
Black Beauty		Early Fellow
Red		All dents
Ohio Yellow		All sweets
Amber Pearl		
Yarling Yellow		
Strawberry		
Baby Golden - 2		
Tom Thumb		

"Any 'normal' variety is readily fertilized by pollen from any other corn including dent and sweet varieties. Any 'cross sterile' variety can be fertilized only by pollen of itself, by another 'cross sterile' or 'neutral' variety, or by a hybrid involving a 'cross sterile' or 'neutral.' A 'neutral' variety is perfectly fertile with any other corn either as a pollen parent or as a seed parent" (Brunson, 1955).

The cross sterility gene may be transferred from one inbred to another. Work in progress by Nelson (1953) should yield cross sterile counterparts which might aid in producing hybrid seed free from dent contamination.

13. DISEASE RESISTANCE AND TOLERANCE

In the United States, the average annual loss from plant diseases is at least 3,000 million dollars. Maize is damaged by many diseases. Intensive methods of production have resulted in serious disease problems These problems are very important because of the extremely large production and value of the crop. Control of plant diseases involves the use of resistant or tolerant hybrids, crop rotation, field sanitation, and soil management. Sprays and dusts are effective in some cases.

Some excellent reports on maize diseases have been published by Koehler and Holbert (1930), Dickson (1947), Ullstrup (1955), and Hayes, Immer and Smith (1955). The 1953 Yearbook of the United States Department of Agriculture was devoted entirely to plant diseases.

Maize diseases may be divided into those caused by non-parasitic factors and those caused by parasites. The more important parasitic diseases may be grouped into seedling infections, leaf blights, stalk and ear rots, smuts, and rusts. Spores of some of the fungi that cause maize diseases are shown in Figure 61. Some of these diseases are important in some areas and relatively unimportant elsewhere, while others are important wherever maize is grown. Losses from these diseases range from very little damage in some years to perhaps 25 percent or more in others.

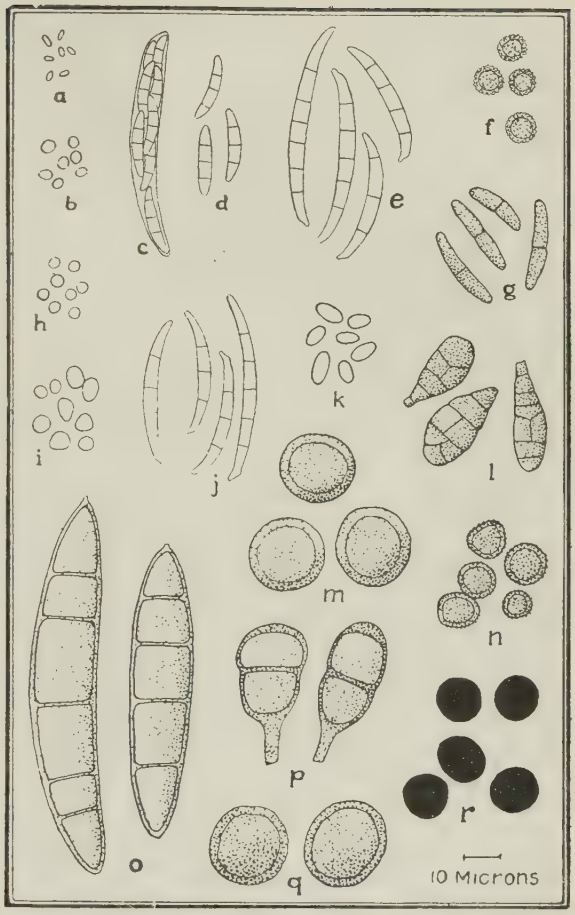
Sources of Resistance

Fortunately, inbred lines and hybrids of maize differ in resistance to diseases. A summary of disease ratings on a large group of inbred lines is given in Tables III and IV, in the Appendix. In these Tables, relative resistance to certain diseases is reported in grades. A grade of 1 denotes the greatest amount of resistance, while a grade of 5 signifies extreme susceptibility. Other sources of resistance are given by Stevenson and Jones (1953), Koehler and Jugenheimer (1950), and by Ullstrup (1950). No doubt many new sources of resistance will be discovered in open-pollinated and hybrid material not yet studied.

FIGURE 61. - *Spores of some of the fungi that cause maize diseases. Drawn with Camera lucida. All enlarged to same scale.*

(Courtesy, B. Koehler and J. R. Holbert, 1930)

(*a*) Cephalosporium acremonium;
(*b*) Penicillium oxalicum;
(*c*) *ascus,*
(*d*) *ascospores, and*
(*e*) *conidiospores of* Gibberella saubinetti;
(*f*) Ustilago zeae;
(*g*) Diplodia zeae;
(*h*) Aspergillus niger *sp.*;
(*i*) Rhizopus tritici;
(*j*) *macroconidia and*
(*k*) *microconidia of* Fusarium moniliforme;
(*l*) Alternaria *sp.*;
(*m*) Physoderma zeaemaydis;
(*n*) Sorosporium reilianum;
(*o*) Helminthosporium turcicum;
(*p*) *teliospores and*
(*q*) *urediniospores of* Puccinia sorghi;
(*r*) Basisporium gallarum.



Inoculation Techniques

Breeding for disease resistance is an important phase of a maize improvement program. If possible, tests for resistance should be conducted on sites where incidence of disease may be expected to be extremely high, the exposure severe and uniform, and other conditions conducive to efficient research (Coons, 1953). Often, however, disease resistance studies are handicapped by insufficient or nonuniform infection. Under such circumstances it is difficult to determine whether a healthy plant is resistant or has escaped the disease. Artificial inoculation is an efficient aid in breeding for disease resistance. The maintenance of disease nurseries and the manipulation of cultural operations to increase disease exposure are other useful aids.

Andrew (1954) discussed diseases of maize at the Seventh FAO

TABLE 22. — SUMMARY OF INOCULATION TECHNIQUES FOR MAIZE DISEASES

Fungus	Time of inoculation	Procedure	Frequency of inoculation	Appearance of symptoms
Ustilago Maydis	15-20 days before tasseling	With needle in upper whorl	Once	By flowering time
Helminthosporium turcicum	When plants are 12-18 in. tall	With compressed air sprayer in top whorl	2 times per week for 3 weeks	After 14-17 days
Helminthosporium maydis	When plants are 12-18 in. tall	With compressed air sprayer in top whorl	2 times per week for 3 weeks	After 6-8 days
Helminthosporium carbonum	When plants are 12-18 in. tall	With compressed air sprayer in top whorl	1-2 times	After 6-8 days
Puccinia sorgi	Greenhouse seedlings in 2-4 leaf stage	Shake dry spores over seedlings	Once	After 10-14 days
Bacterium stewartii	Greenhouse seedlings in 2-4 leaf stage	With needle in stalk and sheaths 8-12 inches above ground	Once	A ter 2 weeks
Diplodia zeae (Stalk rot)	5-10 days after silking	With needle in stalk at first internode above ground	Once	After 1 month
Gibberella zeane (Ear rot)	5-10 days after silking	With infected barley kernel under husk	Once	After 1 month
Gibberella fujikuroi (Ear rot)	At silking	Spray water suspension of spores over silks	Once	After 1 month

SOURCE: Andrew, 1954.

Hybrid Maize Meeting held at Belgrade, Yugoslavia. His summary of inoculation techniques is shown in Table 22. Additional techniques are available.

Ullstrup (1952) published detailed procedures for inducing artificial epiphytotics of leaf blights of maize. These techniques may be used in efforts to breed for resistance to these diseases:

" *Northern and southern corn leaf blight.* Original cultures of the organisms may be isolated as follows: Leaf lesions collected from the previous year's crop are placed in a moist chamber. Four to five days later newly formed spores on the surface of the lesions are picked up with the aid of a fine flattened needle and a dissecting microscope of 30 to 60 power, placed in a droplet of sterile water and streaked across the surface of hardened acidified water agar in petri plates. After allowing a few hours for the spores to germinate, they are cut out of the agar and transferred to hard, acidified potato-dextrose agar. After two weeks of incubation at 75 to 80 degrees F. these cultures may be used to transfer to fresh plates of acidified potato dextrose agar in preparation of inoculum.

When fungus growth has covered the surface of the agar they are ready for use. About 20 petri plates of culture are macerated in water in a Waring blender for 15 to 30 seconds, strained through a layer of cheese cloth and made up to a gallon of suspension. This stalk suspension is taken to the field and diluted in a compressed air sprayer at the rate of 1 quart in about 3 gallons of water. Four quarts of stock suspension diluted as indicated is enough to inoculate about 1,000 plants.

Inoculum should be directed into the whorls of the plants, where it will be retained long enough to permit spore germination. If inoculum is sprayed over the leaves, it evaporates before germination. Spray nozzles may be removed or left on. If removed, more inoculum is used. Inoculations should be made at least twice per week for three weeks beginning when the plants are 12 to 18 inches high. On the basis of 1,000 plants this will require 120 petri plates of pure, uncontaminated cultures.

This method has been uniformly successful over several years in establishing heavy infection so that resistant plants could be selected before silking. Cultures of *H. turcicum* and *H. maydis* may be used together in making up the stock suspension to permit selection for resistance to both diseases.

A somewhat simpler — but less certain — method is to spread infected leaves of the previous year's crop between the rows. When ample moisture is present, spores develop on the old lesions and spread to the young plants. This method may not be successful under extended periods of dry weather. Infected leaves may be ground finely and dusted on leaves of the plants to be evaluated for resistance.

Helminthosporium leaf spot: The method used for field inoculation is essentially the same as described above, except that one or two inoculations are sufficient to establish heavy infection. To inoculate seedlings in the greenhouse, the spores are washed from five plates of culture, suspended in a pint of water and this sprayed over the plants. This amount of spore suspension is ample for inoculating 1,000 to 1,200 seedlings. The plants are held in a moist chamber over night in order to keep a film of water on the leaves for spores to germinate. Susceptible seedlings can be distinguished within one week after inoculation.

Stewart's wilt: Pure virulent cultures of the bacteria are grown on the surface of a suitable agar substrate, washed off after 48 hours, then injected into the stalks of plants 8 to 12 inches high with a hypodermic needle. About

FIGURE 62. - *Diplodia stalk rot inoculations can be made easily, quickly, and efficiently with this inoculator. It is light weight, has large capacity, is easily filled, and is equipped with a durable, troublefree, hollow needle.*

(Courtesy, Illinois Agricultural Experiment Station, Report for 1947-48)

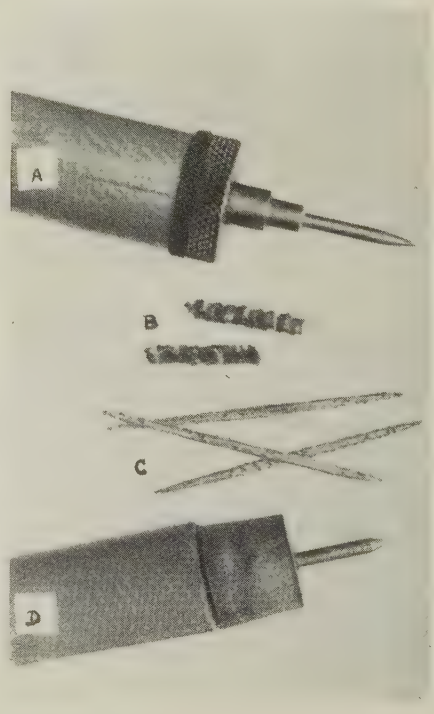


FIGURE 63. - *Apparatus for making stalk inoculations.*

(Courtesy, B. Koehler)

(A). *Needle end of the inoculator shown in Figure 62. Cross hole in needle is $^3/_8$ inch from the point. The remainder of the apparatus is simply an aluminum tube 16 inches long with an adjustable air valve at the other end.*

(B). *Pieces of pipe stem cleaners which are soaked in spore suspensions and pushed into stalks.*

(C). *Toothpicks containing Diplodia culture. The dots are Diplodia pycnidia.*

(D). *A punch for making holes in stalks for inserting pipe stem cleaners or toothpicks.*

two weeks later the disease will have developed sufficiently to permit selection of resistant plants. This method has been used successfully on sweet corn but probably does not furnish a reliable test of resistance in dent corn to the late infection phase of the disease. No satisfactory method has been worked out to simulate the late infection phase initiated by wounds caused by feeding of corn flea beetles."

Smith, Hoppe and Holbert (1938) and Jugenheimer (1940) compared the incidence of Diplodia stalk rot under conditions of natural infection and artificial inoculation. Extremely high correlations were obtained between natural infection and broken stalks, and between natural infection and cortical spread or pith spread with artificial inoculation.

Cultures of the Diplodia fungus on cooked oats should be started about six weeks before they are needed. About six weeks' growth with exposure to indoor daylight is necessary to get good sporulation (Koehler, 1951). The original culture should be selected for its ability to sporulate well under these conditions. These cultures should be thoroughly macerated in water before use, and the larger solid material should be removed by filtering through a fine screen.

Stalk inoculations with *Diplodia zeae* may be made with a water suspension of spores in an inoculator. Inoculations can be made easily, quickly, and efficiently with the inoculator developed by Jugenheimer (Figure 62). It is light weight, has large capacity, is easily filled, and is equipped with a durable, trouble-free, hollow needle. This instrument holds about 4½ ounces of liquid and will inoculate about 300 plants at one filling. In use, the inoculator is held at an angle with the needle downward. The valve controls the amount of air that controls the flow of inoculant. The needle is jabbed into the center of an internode about 12 inches from the ground. The collar of the needle regulates the depth. A drop of the inoculum is sufficient. Inoculations are usually made soon after pollination. Relative resistance may be measured by:

1. the number of rotted internodes;
2. premature dying of the plants;
3. pycnidial development on the surface of the stalks.

Another inoculation method involves the use of pipe-stem cleaners cut into one-inch lengths. These are boiled in water, drained, and dried. They are soaked in a spore suspension of Diplodia just before use. Holes are made in the stalks with a suitable punch, and the pipe cleaners are inserted and left there.

Another method of inoculation utilizes round toothpicks. They are boiled in water and packed into one-pint Mason jars in a vertical position. The cultures are prepared directly on the toothpicks. The Diplodia usually forms pycnidia full of spores on the toothpicks. Holes are punched in the stalks, and the toothpicks are inserted and left there.

Koehler (1951) compared the efficiency of the three methods of making Diplodia inoculations (Figure 63). Three different measurements of infection included:

1. premature dying of plants;
2. number of rotted internodes;
3. pycnidial developments on the surface of the stalks.

Results obtained from the three methods were similar.

Koehler (1951, was not successful in making stalk inoculations with *Gibberella zeae* using these three methods. Gibberella cultures vary in growth, habits, sporulation on media, and pathogenicity.

Koehler (1951) showed that the prevalence of ear rot was modified by husk protection, ear declination, and physiologic resistance within the ears. He was able to increase ear rots for selection purposes by:

1. opening the husks by hand about 20 days after pollinating;
2. inoculating the ears with a pressure sprayer or a medicine dropper.

He was able to increase ear rots to epidemic proportion with *Diplodia zeae*, *Gibberella zeae*, and *Fusarium moniliforme* by one or the other of these methods.

Breeding for resistance to smuts and rusts has been complicated by the occurrence of physiologic races of the pathogen and by lack of a completely satisfactory method of artificial inoculation. Dependence on natural infection has permitted selection of inbred lines and hybrids that are resistant to *Ustilago maydis*.

Reporting Differences in Resistance

Uniform methods for reporting maize disease ratings were outlined by Ullstrup, Elliott and Hoppe (1945) as follows:

"*Seedling blights.* The recommended method for recording incidence and severity of seedling diseases is included here primarily for those studying the comparative efficiencies of fungicidal dust treatments:

1. A general comparison of the fungicidal value of seed treatments may be obtained by recording the percentage of emergence when seedlings have attained the three-leaf stage.
2. For a more detailed study, a seeding population may be divided into the following classes, each of which is assigned an arbitrary value:

Normal size = 1.0
Stunted = 0.5
Blighted after emergence = 0.25

Where seedlings are examined for lesions, normal size plants may be further divided:

Sound = 1.0
Lesioned = 0.75

The number of individuals in each class is multiplied by the class value, and the products are added to obtain a 'fungicidal index.'

Diplodia stalk rot (natural infection). In those areas where diplodia stalk rot occurs rather consistently from year to year, relatively reliable readings may be obtained without recourse to artificial inoculation. Under such conditions the percentage of plants showing definite symptoms of Diplodia stalk rot is recorded. A plant is not recorded as infected unless at least one half of an internode shows definite discoloration or unless the rot has just started and is progressing rapidly. Small, restricted lesions at the nodes are disregarded.

Diplodia stalk rot (artificial inoculation). Where artificial inoculation is employed, the number of internodes and fractions thereof showing definite signs of infection are recorded. Plants prematurely killed as a result of rapid progress of the diseases are given a value of 5. Observations on Diplodia stalk rot should be made before the disease has progressed to the point where differentials, particularly between susceptible materials, may be obscured. Furthermore, if observations are delayed to the stage where healthy stalks have lost their natural green color, considerable difficulty may be encountered in differentiating between diseased stalks from those that have matured normally.

Helminthosporium turcicum leaf blight. Plants may be classified as follows:

Numerical grade	*Degree of infection*
0.5	Very slight infection - one or two restricted lesions on lower leaves.
1.0	Slight infection - a few scattered lesions on lower leaves.
2.0	Moderate number of lesions on lower leaves.
3.0	Abundant lesions on lower leaves, few on middle leaves.
4.0	Lesions abundant on lower and middle leaves extending to upper leaves.
5.0	Lesions abundant on all leaves; plants may be prematurely killed by blight.

No 0-class is included since to date no strain of maize has yet been found to be immune. Where infection is so light that some plants show no infection, it is doubtful if satisfactory differentials could be obtained. It may be deemed necessary in some circumstances to indicate difference in severity between two of the above classes, as for instance between classes 3 and 4. Such cases may be classified as 3.5, but an effort should be made to keep within classes wherever possible. It may be justifiable to reserve such smaller degrees of rating for differentiating between highly resistant or very susceptible materials.

Stewart's disease (late infection). Plants may be classified as follows:

Numerical grade	*Degree of infection*
0	No infection.
1	Trace of infection - a few restricted lesions.
2	Light infection - scattered lesions on lower leaves.
3	Lower leaves ragged and some lesions on tips of middle leaves.
4	Lower and middle leaves ragged, some lesions on upper leaves.
5	Plants killed prematurely by the disease.

Frequently, Helminthosporium leaf blight and Stewart's disease occur in the same planting. If possible, separate ratings, should be made for each disease. Where separate ratings cannot be made, the relative severity of each disease may be recorded and a rating made on the disease occurring in greatest abundance.

Smut. The simple recording of the percentage of plants showing infection is generally used. Additional information such as size and location of smut galls may be of value under some circumstances.

Ear rots. In most uniform single-cross performance tests, grain damage separations are made giving an over-all picture of the relative resistance of the hybrids and their component inbreds to ear rots in general. In some seasons, environmental conditions may be particularly favorable for the development of one or a number of ear diseases. Under such conditions valuable information may be obtained on the relative resistance of hybrids and inbreds to specific ear rots. When the incidence of one or more ear rots is sufficiently high to obtain good differentials the recording of the percentage of ears infected with specific diseases is recommended.

General recommendations. It is recommended that all observations be made on a minimum of 20 plants in any replication in the case of Diplodia stalk rot and ear rots; and that at least 3 replications be included in the final data. In uniform single-cross performance tests, individual plots are generally 2×10 hills involving 40 to 60 individual plants, with each entry replicated 3 to 6 times. In these tests, it is recommended that observations be made on all ears or stalks in a given replication and that at least 3 replications be included.

Final records of disease prevalence and severity in systematic single-cross tests may be conveniently summarized in two-way tables in which the mean values for all replication are entered and from which the grand means of component inbreds are calculated."

Inheritance of Resistance

The maize breeder needs to know something about the inheritance of resistance if he is to utilize inbred lines, differing in resistance, in hybrid combinations. Ullstrup (1950) pointed out that, in general, the resistance of a hybrid to any disease is proportional to the number of resistant inbreds that were combined to make the hybrid.

The degree of resistance of the parental inbreds also influences the degree of resistance of the hybrid. In some cases, dominance of resist-

ance or susceptibility to a disease, or interaction of genetic factors, may complicate this general relation. Information on the inheritance of resistance is given in the section of this chapter devoted to specific diseases. Definite genetic explanations are handicapped by such factors as heterosis, multiple genes, polyploidy physiologic races of causative organisms, and the effects of environment (Stevenson and Jones, 1953).

Nature of Resistance

The nature of resistance to diseases is thoroughly reviewed by Wingard (1941, 1953) and Dickson (1947). An important economic gain is possible through the development and use of immune or highly resistant varieties and hybrids, which lessens the loss from disease and the costs of sprays and other methods of combating diseases. Obviously, a knowledge of the nature of resistance to diseases is essential to such a program.

The ability of a plant to remain relatively unaffected by disease because of inherent properties it possesses is termed resistance. Various degrees of disease resistance are possible. Complete resistance to disease is termed immunity. Immunity is absolute; resistance and susceptibility are relative. A plant may vary from extreme susceptibility to high resistance or complete immunity.

Resistant plants have the ability to withstand, oppose, lessen, or overcome the attack of a pathogen. Susceptible plants are not able to defend themselves against an organism or overcome the effects of invasion. Physical properties of the plant, such as natural openings, hairiness, rough outer wall, waxy coating of stems, and chemicals produced by the plant, may be responsible for immunity.

Disease escape must be clearly distinguished from resistance. Plants may possess no natural inherent resistance to the disease, but still avoid infection. Such plants may possess some quality, such as earliness of maturity, that prevents successful inoculation.

The ability of a plant to endure the invasion of a pathogen without showing any symptoms or much damage is termed tolerance. Plants may be tolerant because of their ability to grow and produce normally in spite of a disease attack. They may have exceptional vigor or perhaps a hardier structure than other plants. Genetic strains differ in their degree of tolerance.

Wingard (1953) re-emphasized the fact that the different degrees of disease resistance displayed by plants are not fixed or absolute. Environmental factors may modify them greatly. Temperature, moisture, fertility, and reaction of the soil may affect disease development. Light, temperature, and humidity are other important factors. Age and matur-

ity of the plant also affect disease resistance. Interactions of the degree of virulence of the pathogen, age and condition of the plant, and the environment affect susceptibility to diseases.

Morphological structures and physiological processes in plants also affect disease resistance. The nature of resistance may be chemical, physiological, morphological, or anatomical. Such factors affecting disease development include natural avenues of entrance for the parasite, tissue barriers, type of embryonic development, rate of tissue maturation, and presence or absence of suitable nutrient complexes or single compounds.

Young pericarp tissues are a desirable medium for many parasitic fungi. Johann (1935) pointed out that the semipermeable membrane holds soluble reserves within the kernel and serves as a barrier to prevent fungi and bacteria, in the pericarp from entering the endosperm and embryo. Mechanical injury of the membrane permits rapid invasion of the endosperm reserves and embryonic tissues by soil micro-organisms during germination. Other parasites invading through the ovary wall must enter soon after pollination before this avenue is barred.

Differences in maturation and composition of seedling tissues affect the degree of resistance to seedling blights. Cortical-invading fungi obtain entrance through the emergence of seminal roots and through the cortex of the lower internode and cotyledonary node.

The structure and development of the basal tissues of the culm or crown affect resistance to crown rot and stalk rot diseases. Smut may enter the plant at the top of the leaf whorl, where it comes into contact with embryonic or susceptible tissues and causes infection. A leaf sheath having a tightly encircling ligule may prevent the inoculum from reaching the younger, susceptible tissues.

Dead anthers and pollen lodging behind leaf sheaths furnish excellent nutritive media for the initial development of some blight and rot fungi. Natural openings, such as stomata, provide avenues for entrance of such organisms as rust fungi. The more basic type of resistance to rusts, however, is associated with cellular composition and physiology.

The rate and character of cuticle formation on epidermal surfaces affects disease development. In general, resistance to mechanical penetration increases as this surface membrane matures and thickens. By preventing wetting and uniform distribution of water over exposed tissue surfaces, the cuticle, hairs, and surface structures restrict the distribution of inoculum and help to keep parasites from penetrating the surface directly or entering through natural plant openings. Suberized cell walls retard the advance of parasitic organisms.

Plant wounds sometimes activate the rate and type of thickening of cellular structures. Changes in composition associated with maturation of many tissues affect resistance and susceptibility to certain diseases.

Plant defense mechanisms involve the chemical and physical properties of cell protoplasm. The composition and physical state of cell protoplasm may affect resistance to cold and drought.

The pathogenic characteristics of the parasite may vary with mutation, segregation, and nuclear reassortment. Variability in lower plants was reviewed by Stakman (1940).

Nonparasitic Diseases

Maize is susceptible to a number of nonparasitic diseases which are usually associated with stalk and leaf symptoms. These maladies may be caused by abnormal temperature, moisture relations, and mineral deficiencies. Certain chlorophyll deficiencies of seedlings are expressed during periods of low temperatures. Low light intensity and low temperatures often cause the virescent types to be expressed. Heat and drought cause leaf burning and decreased yields. Mineral deficiencies usually cause characteristic symptoms. Low magnesium, potash, and other elements often result in abnormal growth and performance (Dickson, 1947). Reactions of various inbred lines to leaf burning, cold soils, and magnesium deficiencies are shown in Table I, in the Appendix.

Seedling Infections

Infections of maize seedlings were recently discussed by Hoppe (1953). He emphasized that the germination period is a critical one in the life of a maize plant. Seed infections can be determined by germination or plating tests. Common fungi which cause seedling infections include *Diplodia zeae*, *Gibberella zeae*, *Fusarium moniliforme*, *Nigrospora oryzae*, and species of *Penicillium*, *Aspergillus*, and *Pythium*. The subject of seedling infections is discussed in considerable detail in the section on "cold tolerance" in Chapter 10.

Seed infection symptoms are similar. In cold, wet soils, the seed decays or the seedlings die before they emerge. In warmer soils, the seedlings may emerge but may be blighted or stunted.

Maize germinates rapidly in warm soils, and sound seed tends to be highly resistant to soil-borne diseases. Reaction of maize inbred lines and hybrids to seedling diseases is influenced by the genetic constitution of the parental inbred lines. Resistance to the disease is often determined by the female, or seed, parent. The pollen parent often is much less important.

Other factors affecting maize disease infection include inferior seed caused by immaturity, frost, old age, physical injury, or improper curing or storing. Injured seeds have little chance to survive when planted in cold soils unless they are treated with an effective fungicide. Kernel injuries

occur during mechanical harvesting and processing of the seed. Broken seed coats over or near the germ are more damaging than chipped crowns and broken tip caps. Reductions in field stands and ultimate yields are usually nearly proportionate to the amount of injury to the kernels.

Inbred lines differ widely in their inherent resistance to seed rot diseases (Tables I, II, III and IV in the Appendix). Hoppe (1953) pointed out that in severe tests of Wisconsin inbred lines, seedling stands ranged from 0 to more than 70 percent when the highest quality seed was used. Cold tests enable breeders to evaluate their stocks for resistance and permit pathologists to test different fungicides.

Seedling diseases of maize are controlled by planting sound, treated seed of resistant hybrids. Proper seed treatment is very important. Mercury-containing compounds have been replaced largely by organic nonmercurials, such as Arasan, Thiram, Phygon, and Orthocide (Hoppe, 1953). Properly applied as dusts or slurries, these products give good protection under severe conditions. Adequate dosage and good materials are essential for satisfactory results.

Infection of maize seedlings is lessened by using quality seed that is mature and harvested before frost damage. Improved methods of harvesting and processing cause fewer kernel wounds. Care should be used in processing and storage. Temperatures exceeding 110° F. during artificial drying are injurious. Seed should be stored in a cool, dry place.

Leaf Blights

Excellent reviews on the leaf blights of maize have been made by Dickson (1947), Ullstrup (1951, 1952), and Robert (1953). Maize is subject to many different leaf diseases, but only a few cause serious damage. Most of these diseases produce characteristic streaks or spots on the leaves. These lesions usually have spores of the causal fungus on the killed parts of the leaves. Crop residues are usually the source of primary inoculum. Secondary conidial infection may occur after the leaf infections are established. The leaf tissues are injured or killed, and thus the area of green chlorophyll is reduced. Severe infection reduces the vigor and yield of the plant, weakens the stalks, and causes the grain to be light and chaffy. Some of these leaf diseases may cause seedling blight and kill the plant at an early age. They enter all parts of the plant and affect its whole system. Later infection usually affects only the leaves. Hereditary factors and unfavorable environmental conditions and unbalanced supplies of minerals may produce similar symptoms.

Leaf blights vary in prevalence and severity from year to year and from area to area, depending on environmental conditions. These parasitic leaf diseases are favored by high humidity, warm temperatures, humid

FIGURE 64. - *Two Helminthosporium blights. Southern leaf blight* (A), *caused by* H. maydis, *Northern leaf blight* (B, C), *caused by* H. turcicum.

(Courtesy, J. W. Pendleton *et al.*, 1951)

weather and heavy dew. Some of the fungi remain in fields from season to season in residues. Wind or insects spread the infection from plant to plant and from field to field. Soil fertility does not influence these diseases so much as do climatic conditions or the genetic constitution of the host plants.

Northern corn leaf blight (*Helminthosporium turcicum*)

Helminthosporium turcicum is distributed widely over the world and attacks all types of maize. The most severe damage is in humid areas that have heavy dews, abundant rainfall, and warm summer weather. Susceptible plants become affected as they approach maturity. Losses may range from a trace to 50 percent of the grain yield, depending on time and severity of attack. Blighted leaves lose part of their nutritive value, and many of the leaves are lost in harvesting. Early maturing strains of maize are usually more susceptible than later maturing material (Tables III and IV, in the Appendix).

The northern leaf blight (*H. turcicum*) causes long, elliptical, grayish-green or tan spots on the leaves ranging up to 6 inches by 1½ inches in size (Figure 64). These lesions first appear on the lower leaves and may increase until little living tissue remains. The appearance of badly infected plants resembles frost injury. Ears are not attacked and therefore the possibility of carrying the disease on the seed is remote (Ullstrup, 1952).

The disease may be controlled by planting resistant hybrids. Dusting or spraying with Dithane or Parzate helps to control the fungus. Six to eight applications should be made. The first should be applied soon after silking. Seed treatment and crop rotation have little effect in controlling the disease.

Most Corn Belt inbred lines are rather susceptible to *H. turcicum*. Ullstrup (1952), Robert (1953), and others have attempted to transfer resistance from southern United States inbred lines to susceptible Corn Belt inbreds by backcrossing, selfing, and selection. Resistant inbreds

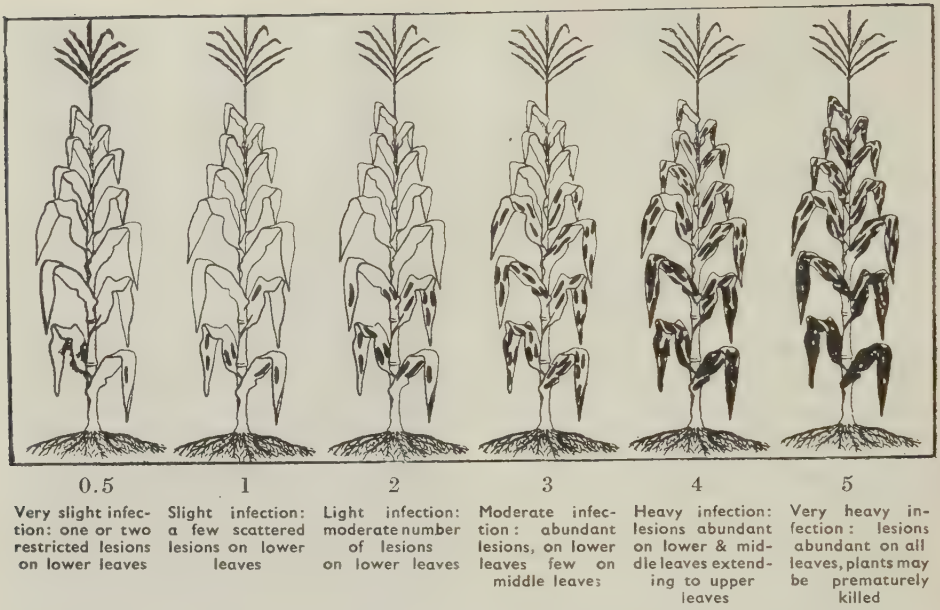


FIGURE 65. - *Scale for estimating* Helminthosporium turcicum *leaf blight.*

(Courtesy, United States Department of Agriculture)

include Mo21A, NC34, L97, T13, Ky114, C.I.23, C103, Ky36-11, K148, K175, K201, K230, C.I.15, and R39. The relative resistance of many other inbred lines is shown in Tables 10 and 11 on page 100 and 118.

Resistance to infection is not clearly expressed until the plants are six to eight weeks old. Therefore, inbred lines cannot be indexed for resistance and resistant plants cannot be reliably selected within segregated generations in the seedling stage in the greenhouse. This work must be done in the field under conditions of heavy disease development (Ullstrup, 1952). Because less than 1 percent of the plants in an F_2 generation are usually highly resistant, and resistance is determined by many genes, a breeding program requires relatively large segregating populations. Jenkins, Robert, and Findley (1954) demonstrated that recurrent selection was an effective method for concentrating genes for resistance to *H. turcicum* leaf blight.

Jenkins and Robert (1952) found that the resistance of inbreds NC34 and Mo21A was most dominant, that of L97 was intermediate, and that of T528 and C.I. 23 was least dominant in reaction with R4. Inbreds NC34 and Mo21A, each carried a major gene for resistance. Three susceptible inbreds, R4, 38-11, and K64, differed materially in reaction with the resistant inbred NC34. Inbred R4 was shown to carry a major recessive gene contributing to extreme susceptibility. These authors concluded

that resistance to *H. turcicum* was controlled by a rather large number of genes.

Most breeders classify the relative resistance of plants in six grades; A grade of 0 indicates immunity; a grade of 0.5, very slight infection; and a grade of 5.0 indicates extreme susceptibility. The other three fall between these ratings. The scale for estimating *H. turcicum* leaf blight is shown in Figure 65.

Southern corn leaf blight (*Helminthosporium maydis*)

Helminthosporium maydis is responsible for southern leaf blight. This disease is found wherever maize is grown under warm, humid conditions. It appears to thrive better at higher temperatures than does the northern leaf blight.

Typical lesions of southern leaf blight range up to 1½ by ¼ inch in size (Figure 64). The lesions are oblong, have parallel sides, and are tan or straw colored. They are smaller and lighter in color than those of northern leaf blight. (Ullstrup, 1952). The disease kills the green tissue of the leaves. Reducing the effective leaf area may reduce grain yield, weaken the stalk, and cause the fodder to be poor in quality. Badly damaged fields may appear to be fired.

Developing and using resistant hybrids is the best way to control southern leaf blight. Rotation or seed treatment is of little value. Ullstrup (1952) lists the following inbred lines as being resistant to the disease: C103, Tr, MoG, W20, M14, Os426, 33-16, Ky27, H22, and K64. The relative resistance of additional inbred lines is shown in Tables III and IV, in the Appendix.

Ullstrup (1952) says that resistance to this disease appears to be inherited in a manner similar to that of *H. turcicum*. However, it is governed by a different set of genes. Breeding for resistance is made more efficient by using artificially induced epiphytotics. Resistance to southern leaf blight is not clearly expressed in the seedling stage. Therefore, plants should be classified for disease reaction under heavy infection in the field. In a breeding program, it is possible to inoculate with *H. turcicum* and *H. maydis* at the same time in order to select for resistance to both diseases.

Helminthosporium leaf spot (*Helminthosporium carbonum*)

Helminthosporium leaf spot is caused by *H. carbonum*. The two known physiologic races of the fungus produce different symptoms, although neither is of great economic importance. The two races are similar in size, shape, and color of spores. The disease caused by Race I destroys susceptible inbred lines. Most inbreds, however, are resistant to the disease. Humid conditions favor the development of the fungus.

Ullstrup (1952) states that the disease caused by Race I produces tan lesions on the leaves ranging in size to 1 inch long by ½ inch wide. Lesions are oval or circular, with concentric zones within the affected area. The leaves of susceptible inbreds may be covered with lesions. The disease also attacks the ears, giving the kernels a characteristic charred appearance. Race II of the fungus produces oblong, chocolate-colored spots ranging to 1 inch by ¼ inch in size.

Susceptibility to infection by *H. carbonum* Race I is determined by a single recessive gene, hm. (Ullstrup, 1941) located on chromosome I (Ullstrup and Brunson, 1947). The recessiveness of this gene accounts for the minor economic importance of this disease. When a susceptible inbred line is crossed with a resistant inbred line, the hybrid is resistant. The order of the genes is P-hm-br-f_1. The gene, hm, lies 33 units to the right of the P locus and 14 units to the left of the br locus. Apparently one or more modifying genes in some inbred lines inhibit the full expression of susceptibility. Inheritance of susceptibility to infection by *H. carbonum* Race II probably involves a number of genes.

Helminthosporium leaf spot can be controlled by using resistant inbred lines. Since only one gene determines susceptibility and since a 1:1 ratio of resistant to susceptible plants is expected in the back cross, only 10 or 12 plants are required to effectively select resistant types in a back-cross generation. Inbred lines Pr, Mo21A, K61, K44, and NC37 are susceptible to Race I (Ullstrup, 1952).

Ullstrup (1952) gave two examples of breeding for resistance to this disease. Inbred lines Mo21A and Pr are susceptible. Outcrossing these lines with resistant inbred lines and backcrossing for five to seven generations made it possible to select resistant recoveries that are similar in all respects to the original inbreds except that they are resistant.

Stewarts disease (*Bacterium stewartii*)

Bacterium stewartii is responsible for the most important of the bacterial leaf diseases of maize. This disease is known as Stewarts disease, Stewarts wilt, Stewarts leaf blight, or bacterial wilt. It is most severe on sweet corn but also attacks susceptible varieties of dent, flint, flour, sweet, and popcorn varieties. According to Robert (1955), the combined effects of bacterial wilt in sweet corn and leaf blight in dent corn are of considerable importance to maize growers.

In general, Stewarts disease does most damage to sweet corn. Before resistant hybrids were developed, the wilt destroyed large acreages of sweet corn in the United States and was largely responsible for the shift in canning acreage to the Northern part of the country. The disease has been reported in the United States, Mexico, Puerto Rico, Italy, South Africa, Canada, Costa Rica, and the U.S.S.R.

Robert (1955) differentiates between "bacterial wilt" and "Stewarts leaf blight" in a recent bulletin. She states that:

"Bacterial wilt and Stewarts leaf blight are caused by a species of bacterium. Individual bacteria are microscopic, nonmotile rods less than one twelve-thousandths of an inch long. These bacteria get into the corn plants through wounds in the leaf tissue made chiefly by the feeding of corn flea beetles. Infected seed may also cause a young seedling to become affected with the bacteria. Once inside the leaf, the bacteria may multiply until they fill the water-conducting vessels of the veins of the leaf. This causes dead streaks in the leaf and sometimes large areas are killed, causing Stewarts leaf blight. If the bacteria spread through the leaf veins into the stalk and fill many of the water-conducting vessels in the vascular bundles, they prevent the plants from getting water and food materials and thus cause bacterial wilt. The bacteria may spread also through the stalk into the tassel and ear, and the infection may become general throughout the plant.

The symptoms of bacterial wilt found mostly on sweet corn are somewhat different from those of Stewarts leaf blight found mostly on dent corn.

Susceptible sweet corn varieties are subject to infection with bacterial wilt throughout their growth. Young infected plants in the field often wilt as if suffering from lack of water. The green leaves dry up one after another and the whole plant may wilt and die, even though there is plenty of moisture in the soil. Those that do not die become stunted, tassel prematurely, and produce no ears or, at most, only nubbins. Long, wilted, pale-green streaks with irregular or wavy margins develop in the leaf blades. These streaks may start from wounds made by flea beetles feeding on the leaves, usually on the tip half. The streaks may turn a pale yellow and die through the center and may spread along the veins into the stalk and dwarf or kill the entire plant. The vascular bundles, or water-conducting channels, of the stalks may become so filled with bacteria that when the stalks are cut crosswise masses of the bacteria ooze out as yellow, moist beads on the cut ends. Bacteria also may spread into the tissues along the vascular bundles of the stalks and form cavities in the pith.

Ears may become infected. Usually only part of the kernels are diseased, but all kernels of heavily infected ears may be damaged. Bacteria may spread through the shank and cob into the interior of the kernels. They also may come out in tiny drops on the inner surfaces of the husks and become smeared over the kernels. Small, irregular water-soaked spots on the inner and outer husks later become dried and darkened.

Young plants of dent corn are more resistant to bacterial wilt than are those of sweet corn. In spite of flea beetle feeding injuries, only a few young plants of dent corn become infected and very few develop bacterial wilt symptoms.

On susceptible dent corn Stewarts leaf blight is recognized by the conspicuous streaks on the leaves. They generally appear on the leaves of susceptible plants when they are in tassel. At first they are light green to yellow and extend along the leaf veins with irregular or wavy margins. When they become older they turn tannish brown and dry. When the streaks are numerous they blend together and large areas of the leaf become involved. Sometimes entire leaves die and dry up. This premature firing or dying of leaves while the stalks remain green gives the plants the appearance of having suffered frost damage.

On resistant dent corn the streaks on the leaves are less abundant and considerably smaller. They often become only small oval spots 1 or 2 inches long. When infection is severe, more leaf area is destroyed and yield is reduced. The weakened plants become more susceptible to stalk rots.

The lower leaves usually are infected first, and the disease progresses upward. Rarely do infections in the leaves spread into the stalk and other parts of the plant. Stalks that are cut across, therefore, generally will not ooze yellow bacterial droplets. Ears of dent corn may become infected, but this is not common.

The bacterial wilt and Stewarts leaf blight bacterium overwinters almost exclusively within the bodies of the corn flea beetle, and the beetle carries the bacterium to the young corn plants in the spring soon after the corn comes up. The adult beetles come out of hibernation as the weather becomes warm in April and May and begin to feed on growing vegetation including corn. Infection may spread rapidly from such feeding areas.

It is probable that bacteria can live in seed for several months. Infected seed, therefore, may introduce the disease into uninfested regions or countries. However, only about 2 percent of the plants develop bacterial wilt when infected kernels are planted, thus infected seed cannot account for the heavy disease attacks that sometimes occur early in the season.

The bacteria occasionally may overwinter in soil, manure, or cornstalks, but it has not been demonstrated that plants become infected from these sources.

There is a close relationship between the amount of bacterial wilt and of Stewarts leaf blight that develop and the temperatures of the previous winter. A heavy epidemic of bacterial wilt on sweet corn is not likely to follow when the average temperature for the three winter months totals less than 100° F.

Each year from 1949-54 forecasts of the severity of bacterial wilt and Stewarts leaf blight have been made in Illinois. These have shown that, following mild winters in that State, heavier attacks of bacterial wilt and Stewarts leaf blight occur.

The growing of resistant hybrids or varieties is the only practicable method of controlling bacterial wilt. Many resistant hybrids are available. Since the wilt bacteria may remain alive inside the seed from one season to another, they are not destroyed by surface treatment of the seed. Dry-heat treatments have been tried, but these cannot be recommended as yet. Transmission through the seed is responsible for so small a part of the field infections in the spring that it is of no practical importance. Seed treatments do not protect the plants from infection through feeding injuries of corn flea beetles, which is the source of most of the field infections.

Some of the common early, medium, and late resistant varieties (of sweet corn) used in 1954 are Marcross, Golden Jewel, Gold Rush, Seneca Arrow, Hoosier Gold, Seneca Chief, Iogold, Ioana, Seneca Market, Golden Cross Bantam, Golden Harvest, Golden Security, Calumet, Erie, Tendermost, Huron, Victory Golden, Aristogold Bantam Evergreen, Illinois 10, and Iochief.

Practically all white sweet corn hybrids containing lines of Country Gentleman and Stowell Evergreen are resistant to bacterial wilt. These include Country Gentleman (Ill.) No. 13, Country Gentleman (Ill.) 8 × 6, and Narrow Grain (Ill.) 14 × 11.

Early varieties of flour and flint corns are susceptible to bacterial wilt, but since they are grown only sparingly the disease losses in these types of corn are not serious.

Some dent corn hybrids, particularly early ones, are susceptible to bacterial wilt. Most of the dent corn hybrids adapted in the Corn Belt and in other areas are resistant to general infection.

Popcorn varieties also show differences in susceptibility to bacterial wilt, although information on them is limited. Black Beauty, Tom Thumb, Bear Foot, and Japanese Hull-less have been reported to be very susceptible, and South American and Sunburst to be resistant.

Inbred lines that make up hybrids of dent corn and hybrids themselves show differences in susceptibility and resistance to Stewarts leaf blight. Even though specific breeding for resistance to this disease has not been done and the hybrids now in use have not been tested under heavy epidemic conditions, some are known to show more resistance than others.

Some hybrids that have shown at least a moderate degree of resistance to Stewarts leaf blight and which are now successfully grown in various parts of the United States are: Ind. 252, Ind. 419, AES 702, Ohio C38, Ohio C54, AES 805, Ohio 141, Conn. 870, Kans. 1830, Ill. 200, Ill. 784, Ky. 203, U.S. 523W, Dixie 22, Dixie 33, Dixie 17, N.C. 27, Georgia 101, Dixie 11, Dixie 18, and Dixie 82."

Differences among inbred lines in resistance to Stewarts disease are shown in Tables III and IV in the Appendix.

Wellhausen (1937) found three genes, Sw, Sw_2, and Sw_3, which were dominant for resistance to bacterial wilt. These genes are independently inherited and are supplementary in their behavior. One of these factors was linked with the P gene for cob color. Inoculation helps to select resistant inbred lines. Plants differing in resistance are usually recorded in six grades. A grade of 0 indicates no infection; a grade of 1, a trace of infection and a few restricted lesions; and a grade of 5, plants killed prematurely by the disease. Other grades are intermediate.

Stalk and Ear Rots

Stalk and ear rots caused by fungi cause enormous crop losses. Stalk rots reduce yield and quality and make harvesting difficult. Ear rots reduce the yield, quality, and feeding value of the crop.

Koehler (1951) listed six factors that affect the prevalence of stalk rots:

1. the weather;
2. the amount of infected material carried over from the previous year (crop rotation of minor value because spores are carried widely by wind);
3. leaf injuries caused by diseases, insects, or weather that change the composition of the plant and make it more susceptible to diseases like Diplodia rot;
4. borers making holes through which fungi may enter and cause susceptible material to rot severely;
5. excessively high or unbalanced fertility and heavy plant populations;
6. relative resistance and susceptibility of the hybrids (an important factor that is of great interest to the plant breeder).

Diplodia root, stalk and ear rot (Diplodia zeae)

Diplodia zeae is of major importance in most areas where maize is grown intensively. This disease is very important in the Corn Belt of the United States but is less important in the drier and cooler areas. *D. ma-*

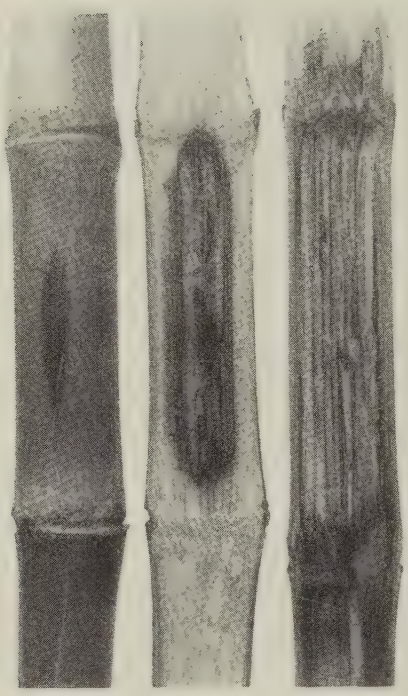


FIGURE 66. - *Maize stalks inoculated with* Diplodia zeae. *Note hole made by injector* (left). *Stalks cut open show a moderately resistant reaction to this rot* (center) *and a susceptible reaction* (right). *Breeders inoculate plants with Diplodia to determine their resistance to this stalk rot.*

(Courtesy, J. W. Pendleton *et al.*, 1950)

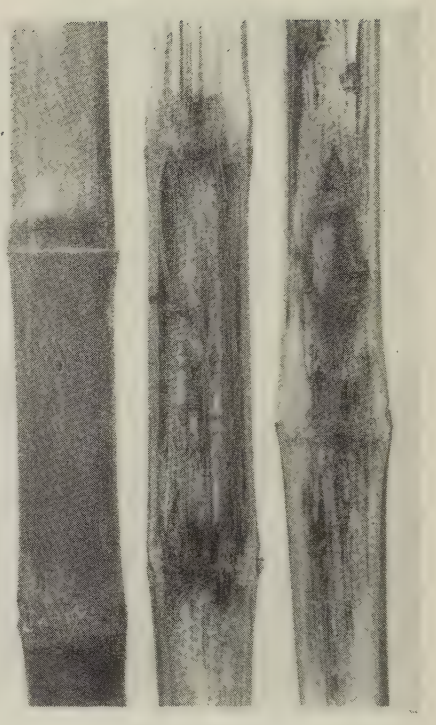


FIGURE 67. - *Maize stalks entered by European corn borer. Stalk* (left) *shows entrance hole. Stalks cut open show extensive Diplodia rot. The borer had probably become polluted with spores of the disease and thus may have served as an inoculator. Stalk rot is often associated with borer damage and may cause even more damage than the borers.*

(Courtesy, J. W. Pendleton *et al.*, 1950)

crospora occurs in the more humid, warm climates, but causes less damage than *D. zeae*. These two organisms are responsible for a considerable amount of seedling blight, stalk breakage, ear droppage, poor quality of grain, and decreased yields. Early infection causes blighted seedlings that show a brown dry rot below the soil surface. Stalk breakage and ear droppage make mechanical harvesting difficult. Mold beginning at either end of the ear may cause rot that extends from only a few kernels to the entire ear.

The fungus enters the stalk near the crown of the plant or through the nodes. Affected plants often appear wilted, as they do when injured by frost. Diseased plants turn brown and the tissues soften at the lower part of the stalk. As the disease progresses, pith tissue is destroyed and only the strands of the water-conducting vessels are left in the stalk.

Factors that affect stalk rot prevalence include differences in resistance of the host, weather, amount of infected material, leaf injuries, corn borers, and soil fertility.

Inbred lines differ greatly in their resistance to Diplodia (Figures 66 and 67). The relative resistance and susceptibility of a large number of inbred lines are shown in Tables III and IV, in the Appendix and by Koehler and Jugenheimer (1950). The best method of control is the use of resistant hybrids. Artificial infection in the breeding program prevents the plants from escaping infection and makes it possible to select resistant material. Inoculations can be made easily, quickly, and efficiently with the inoculator shown in Figure 62. In general, reaction to Diplodia inoculation provides a measure of resistance to stalk rots.

Smith, Hoppe, and Holbert (1938) and Jugenheimer (1940) reported that artificial inoculation was far superior to dependence upon natural infection, although certain precautions are necessary in its use. Strains often cannot be compared directly if they differ greatly in maturity, are grown on different levels of soil fertility, or suffer differently from drought, insects, or other diseases. Stalk inoculations should be made at the time of pollination or shortly thereafter. Relative resistance may be measured as number of rotted internodes, pycnidial development on the surface of stalks, and premature dying of plants.

Data obtained during several years by Jugenheimer (1940) indicate that crosses between resistant and susceptible inbred lines usually approach the resistant parent in resistance. The effects of heterosis, and at least partial dominance of resistance, appear to be factors. Some evidence of supplementary action of resistance factors was obtained when crosses between certain susceptible inbreds were more resistant than either parent. However, crosses between very resistant inbreds were sometimes less resistant than the parent lines. Resistance to most maize diseases tends to be complex and polygenic.

Diplodia ear rot is sometimes a destructive disease of maize ears (Ullstrup, 1953). Early symptoms include bleaching of the husks. Early infection causes the ear to rot completely, becoming grayish brown and shrunken by harvest. Growth of the fungus often makes the husks adhere tightly to the ear. In later infection a grayish-white mold appears on and between the kernels at harvest. Diplodia ear rot usually begins at the butt of the ear and spreads to all of the kernels as it progresses toward the tip.

Natural infection is caused by wind-borne spores that lodge between the husks, where they germinate and penetrate the host tissue. The disease is most prevalent in seasons of dry pollinating periods followed by wet weather. Hybrids with loose husks that permit the ear tip to be exposed, and upright ears that retain moisture between the husks, are often susceptible to infection. Ears are most susceptible to infection

within two to three weeks after silking. Early-drying hybrids tend to be more resistant than slow-drying strains. Differences among inbred lines in kernel rot grade are shown in Tables III and IV in the Appendix.

Gibberella stalk and ear rot and seedling blight (Gibberella zeae)

The prevalence of *Gibberella zeae* fluctuates from year to year, but the disease causes a considerable amount of damage in some areas in certain years. *G. zeae* causes stalk rot, premature dying, and lodging of susceptible maize inbred lines and hybrids.

Seedling blight gives the cortical tissues a water-soaked appearance. The blight usually occurs before emergence or the early seedling stage. Low temperatures increase the amount of blighting.

Gibberella stalk rot is prevalent in northern areas. The pink to brick-red fungus growth discolors the husks, ears, and kernels. Infection usually progresses from the tip of the ear to the base. The spores are carried by wind to susceptible hosts, where they germinate and penetrate in wet weather. Infection is increased by wet weather during silking and by hybrids with loose, open husks.

TABLE 23. — PREMATURELY DEAD PLANTS OF INBRED LINES AND SINGLE CROSSES CAUSED BY DIFFERENCES IN RESISTANCE TO GIBBERELLA STALK ROT

Parent lines	U.S. Cl.21E	Ind. 38-11	Kans. K201C	Kans. K4	Iowa L317	U.S. Cl.7	Kans. Kys.	Kans. K155	Tenn. T8	U.S. Cl.3A
Cl.21E	4/	4	1	14	12	0	12	1	0	10
38-11	4	28/	1	5	10	1	33	24	0	14
K201C	1	1	3/	0	0	0	0	0	2	0
K4	14	5	0	100/	11	0	8	0	2	9
L317	12	10	0	11	82/	5	83	44	26	72
Cl.7	0	1	0	0	5	26/	8	15	0	46
Kys.	12	33	0	8	83	8	14/	7	1	67
K155	1	24	0	0	44	15	7	0/	0	26
T8	0	0	2	2	26	0	1	0	1/	0
Cl.3A	10	14	0	9	72	46	67	26	0	87/
Mean	6	10	0	5	29	8	24	13	3	27

/ Inbred lines.
SOURCE: Jugenheimer *et al*, 1947.

Inbred lines differ greatly in resistance to *G. zeae* (Tables III and IV in the Appendix). As Figure 68 and Table 23 show, Gibberella prematurely killed all of the plants of inbred line K4, but it injured none of the plants of K155. Crosses involving K201C were practically immune,

FIGURE 68. - *Inbreds K4* (left) *and Kys* (right) *were killed prematurely by Gibberella stalk rot, while inbred C. I. 21E* (extreme left) *was resistant.*

(Courtesy, Illinois Agricultural Experiment Station, Report for 1938-47, 1948)

while crosses of L317, C.I.3A, and Kys were very susceptible. Stalk inoculation techniques are not so satisfactory for this organism as for Diplodia. Inheritance of resistance appears to be polygenic.

Nigrospora cob and stalk rot (*Nigrospora oryzae*)

Nigrospora oryzae causes both cob and stalk rot. The disease occurs when development of the maize plant is slowed down or stopped by root injury, light frost, stalk rot, or sudden and acute drought. It appears to be more severe on poor soils than on fertile ones.

Affected ears are light in weight, and kernels are bleached and chaffy. Cobs of susceptible ears have a shredded appearance (Figure 69). Groups of black spores are often seen on the kernel tips.

The disease overwinters on plant refuse in the field. The organism often kills susceptible kernels if they are planted in cold, wet soil.

Control includes the use of adapted full-season hybrids. Inbred lines differ in resistance, but no satisfactory inoculation techniques have been developed to help breed for resistance.

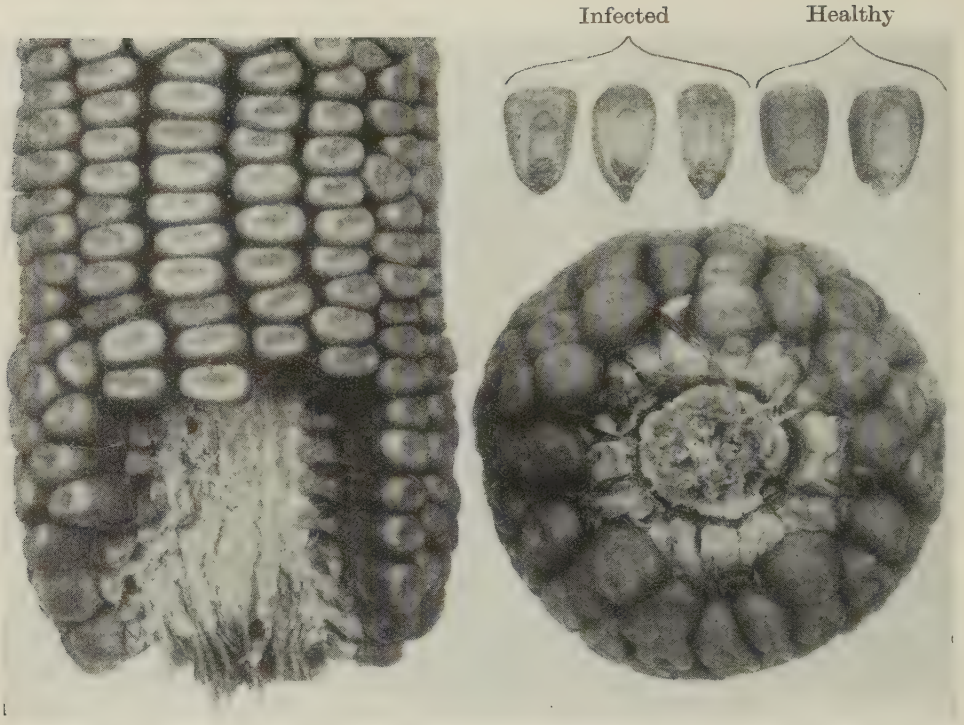


FIGURE 69. - *Cob and kernel rot caused by Nigrospora.*
(Courtesy, B. Koehler and J. R. Holbert, 1938)

Fusarium kernel rot (*Gibberella fujikuroi*)

Ullstrup (1953) states that Fusarium kernel rot is caused by *Gibberella fujikuroi*, a weak parasite that frequently follows infections initiated by more vigorous pathogens. Inbred lines differ in resistance to this disease. Susceptible inbred lines often have " silk-cut " or " popped kernels ". Such lines transmit weak seed coats to their hybrids and tend to be susceptible to Fusarium kernel rot.

Gray ear rot (*Physalospora zeae*)

Physalospora ear rot is serious only in local areas. Early symptoms resemble those of Diplodia ear rot. The disease causes husks to bleach and adhere to each other. Infected ears often have tiny black specks through the cob pith. Kernels from infected ears may have small black specks or stripes beneath the seed coat.

Wind-borne spores germinate and start infection on leaves and ears. Fruiting structures mature the following summer. Wet weather during silking and hybrids with upright ears and poor husk protection favor development of the disease.

Charcoal rot (Macrophomina phaseoli)

Charcoal rot is a serious disease in many areas of low rainfall. It attacks the roots and lower part of the stalk as the plant approaches maturity. The organism destroys the pith and causes internal shredding, leaving the fibrous strands free in the stalk. These strands later become covered with black, " charcoal-like " fruiting bodies that distinguish it from Diplodia stalk rot (Figure 70).

Long rotations and abundant soil moisture, when irrigation is possible, are desirable measures of control. Inbred lines and hybrids differ considerably in resistance, but little breeding work has been done on this disease.

Kernel mold, seedling injury and scutellum rot (penicillium, rhizopus, and aspergillus species)

These three fungi cause kernel mold, seedling injury, and scutellum rot in the more humid areas. They are associated with maturation of the crop and may cause loss of quality and yield. Field control of these diseases is aided by use of hybrids that mature and dry rapidly in the field. Early harvesting and artificial drying also help to prevent damage (Dickson, 1947).

FIGURE 70. - *Charcoal rot destroys the pith and causes internal shredding. Strands become covered with " charcoal-like " fruiting bodies.*

(Courtesy, B. Koehler)

FIGURE 71. - *Common smut may occur on any of the above-ground parts of the maize plant.*
(Courtesy, B. Koehler and J. R. Holbert, 1938)

Pythium root rot (Pythium arrhenomanes)

Pythium species are parasitic on the rootlets of young maize plants. Characteristic symptoms include rotting of the seedlings near the soil surface. The root ruptures from water-soaked lesions that develop on the finer rootlets. In cold, wet soils the rot advances into the main roots or crown tissues. Mycelia develop in the soils in association with crop residues and invade the roots whenever environmental conditions are favorable (Carpenter, 1934).

Control includes the use of resistant hybrids, careful harvesting and processing of seed to prevent breaks in the pericarp, treatment of seed with Arasan, rotation, and balanced soil fertility.

Rhizoctonia rot (Rhizoctonia sp.)

Rhizoctonia species cause root, stalk, and ear rot of maize in warm climates. Husks and kernels are covered with a pink growth of the fungus in early stages of infection. The disease is favored by warm, humid weather.

Miscellaneous Diseases

Smut (Ustilago maydis)

Ustilago maydis is perhaps the best known disease of maize. Although the disease is not carried over on the grain as in many cereal smuts, sufficient inoculum is carried on the seed to aid in its distribution. Losses vary from year to year, depending on environmental conditions. Factors increasing the incidence of the disease include:

1. dry weather in late spring and early summer;
2. heavily manured soils;
3. detasseling in seed fields;
4. pollination failure;
5. hail damage.

Ustilago maydis occurs on all of the aboveground parts of the maize plant (Figure 71). The size, location, and number of galls on a plant determine the effect on yield. Large galls cause more damage than small galls, and galls above the ear are more destructive than those below the ear.

Seed treatment is of little value in controlling *Ustilago maydis* because the organism overwinters on plant tissues in the soil. This disease, however, is easy to control by using resistant material. Breeding for resistance is handicapped by lack of a completely satisfactory method

of artificial inoculation and by the occurrence of physiologic races of the organism. Inbred lines differ considerably in resistance (Tables III and IV, in the Appendix).

Inheritance of resistance to common smut appears to be determined by a relatively large number of genes. Burnham and Cartledge (1939) reported associations between smut reaction and region of interchange in translocation stocks. Saboe and Hayes (1941) reported genes for smut resistance in the short arm of chromosome 6 and in the long arms of chromosomes 7 and 8.

Inbred lines of maize differ greatly in their relative resistance to *Ustilago maydis* (Tables 3 and 4, on pages 14 and 20, and Table 24). Inbred lines 276 and 205 are resistant, while 426 and 159 are susceptible. Crossing the two resistant inbreds resulted in a population with no smutted plants, while crossing the two susceptible inbreds resulted in a population with 60 percent of smutted plants. Backcrossing the (R×S) F_1 to the susceptible parent resulted in more than three times as many smutted plants as when the same F_1 was backcrossed to the resistant parent.

TABLE 24. — EFFECT OF LEAF CLIPPING AND PREVENTION OF POLLINATION ON INBRED LINES AND CROSSES OF MAIZE DIFFERING IN RESISTANCE TO USTILAGO MAYDIS, MANHATTAN, KANSAS, 1938
(Means of 3 replications)

R = resistant S = susceptible	Pedigree	Smutted plants			Lodged plants		
		Treatment			Treatment		
		N[1]	B[1]	C[1]	N[1]	B[1]	C[1]
		Percent					
R	276	12.1	2.8	10.9	46.7	26.7	60.0
R	205	2.0	0.0	3.6	6.7	6.7	6.7
S	426	43.8	51.9	26.3	26.7	6.7	40.0
S	159	—	—	—	—	—	—
R × R, F_1	276 × 205, F_1	0.0	7.5	1.9	20.0	6.7	6.7
S × S, F_1	426 × 159, F_1	60.1	80.5	55.3	0.0	0.0	6.7
R × R, F_2	276 × 205, F_2	3.5	14.0	7.1	20.0	6.7	40.0
S × S, F_2	426 × 159, F_2	71.9	60.0	58.1	20.0	13.3	26.7
R × S, F_1	276 × 159, F_1	15.9	33.4	12.6	33.3	26.7	33.3
R × S, F_1	205 × 426, F_1	3.5	23.4	8.8	13.3	0.0	20.0
R × S, F_2	276 × 159, F_2	24.6	25.2	19.8	40.0	20.0	40.0
R × S, F_2	205 × 426, F_2	12.3	23.6	21.0	26.7	6.7	26.7
(R × R) × R	(276 × 205) × 276	1.8	3.5	1.8	33.0	20.0	20.0
(R × R) × R	(276 × 205) × 205	0.0	8.8	1.9	0.0	0.0	20.0
(S × S) × S	(426 × 159) × 426	55.3	47.3	40.3	13.3	0.0	26.7
(S × S) × S	(426 × 159) × 159	—	—	—	—	—	—
(R × S) × R	(276 × 159) × 276	12.5	7.0	12.6	20.0	13.3	46.7
(R × S) × S	(276 × 159) × 159	38.4	50.9	31.5	26.7	26.7	33.3
(R × S) × R	(205 × 426) × 205	9.2	16.2	7.0	6.7	6.7	20.0
(R × S) × S	(205 × 426) × 426	31.6	31.6	31.6	20.0	0.0	33.3
	Mean	22.1	27.1	19.6	20.7	10.4	28.2

[1] N = Normal plants; B = Barren plants; C = Leaf-clipped plants.
SOURCE: Jugenheimer, unpublished.

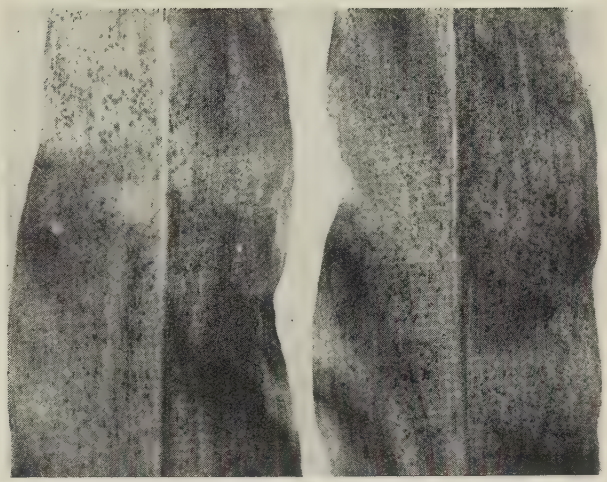


FIGURE 72. - *Corn rust on leaf blades.*

(Courtesy, B. Koehler)

The effect of clipping leaves and preventing pollination on inbred lines and crosses differing in resistance to smut is shown in Table 24. Preventing ears from developing increased smut infection, while removing about 25 percent of the leaf surface about one week after pollination decreased the infection. Apparently resistance to smut is related to concentration of sugars and carbohydrates in the maize stalk.

Rust (Puccinia sorghi)

Puccinia sorghi is the fungus that causes common rust of maize. Usually the disease is of minor importance in the United States, but it may cause a considerable amount of leaf killing in some other countries. Infection that becomes severe by silking time probably causes some actual loss in grain yield (Robert, 1953). Small powdery rust-colored spots appear on the leaves (Figure 72). Later in the season, when the plants are mature, these postules turn dark brown to black.

Moderate temperatures, with luxuriant and succulent growth of a susceptible host favor the development of the fungus. Inbred lines differ in resistance to common rust. Inbred lines WF9, B2, CI. 540, ITE 701, and Ill. 90 have shown resistance under field conditions. In general, inheritance appears to be polygenic, although resistance to physiologic form 3 is a monogenic dominant. Rhoades (1953) used X-ray-induced deficiencies, cytologic examination, and trisomic tests to locate this gene for rust resistance on the long arm of the tenth, or shortest, chromosome of maize.

Puccinia polysora

Puccinia polysora is a fungus that causes southern maize rust. It is difficult to distinguish *P. sorghi* from *P. polysora* on the basis of symptoms. Heavy dews and high temperatures appear to increase infection and spread of the disease.

Southern maize rust has been reported in Mexico, Africa, and Central America. In these areas, rusts are frequently severe and may prematurely kill the plants.

Brown spot (*Physoderma zea-maydis*)

Physoderma zea-maydis causes a disease of maize and teosinte known as Physoderma brown spot. It is of major importance in warm, humid regions where maize is grown (Dickson, 1947). Oblong to round lesions occur on leaf and stalk tissues. The water-soaked, light-green lesions coalesce to form brown blotches. Stalks frequently break as a result of the infection.

High temperatures and abundant moisture are essential to the development of the disease (Tisdale, 1919). Control includes sanitation and the use of resistant hybrids. L87 and L87-2 are resistant lines. Resistance to the disease is probably polygenic.

Witchweed (*Striga sp.*)

Witchweed is a widespread flowering plant that is parasitic on grasses in the tropics and sub-tropics of the Old World. Several species of *Striga* have been reported to cause considerable injury to cultivated crops in South Africa, India, Kenya, Burma and the Dutch East Indies. Witchweed, *Striga lutea*, causes enormous yield losses of maize in South Africa (Saunders, 1933), and has been reported in the United States in North and South Carolina.

According to Saunders (1933), witchweed germinates underground near roots of other plants. Host plants exude a substance from their roots which aids germination of witchweed seeds. Upon germination the *Striga* fastens sucking parts to nearby host roots. Gradually starving the host plant, the *Striga* lives underground for about a month. Then it shoots up stalks eight or nine inches tall with bright green leaves and pink, yellow or white flowers that produce thousands of seeds. When attacked, the maize plants show wilting and yellowing of leaves. The plants become stunted in growth and appear as if suffering from drought. Eventually they shrivel and die. The life cycle of the witchweed ordinarily requires about three months, a third of this time usually is spent underground.

Saunders (1933) states that witchweed can be controlled by clean cultivation, but the task must be undertaken in time and requires extreme thoroughness. Trap-crops, such as maize and Sudan grass, aid in eradicating witchweed from heavily infested soil. Plants can be killed by 2,4-D but dormant seed may remain alive in the soil for many years. Some native strains of sorghum are partially resistant to witchweed.

Present control in the United States is aimed toward preventing seed production and spread of the seed. Attempts are being made to plant some crop which causes the seed to germinate, but which will not support the parasitic sprout.

14. INSECT RESISTANCE AND TOLERANCE

Maize is attacked by many insects. The more important ones are listed in Table 25 on pages 202 and 203. They have been classified broadly by primary place of damage, i. e., underground; stalk, leaf and ear; and stored grain.

Insect-resistant strains of plants are usually better able to avoid, tolerate, or recover from insect attack than are the more susceptible strains. Degree of resistance may range from very susceptible to very resistant. A variety with 100 percent resistance is termed immune. The ability of plants to stand well and produce satisfactory yields when severely attacked by insects is an example of insect tolerance.

Use of maize strains with greater resistance and tolerance to insects would lessen outlays for materials and equipment for control measures, improve yields and quality, and lower production, harvesting, and storage costs.

Sources of Resistance

Many workers have evaluated inbred lines and hybrids for resistance to insect pests. Summaries of insect ratings on many of the inbred lines used in open-pedigree hybrids in the Corn Belt of the United States are given in Tables III and IV in the Appendix. These data — on European corn borers, corn earworms, leaf aphids, thrips, and flea beetles — which were provided by many workers, were summarized by Brunson, Ullstrup, and Dicke (1948, 1949). Bigger and Snelling (1942) compiled the reactions of a large number of inbreds to earworms, leaf aphids, corn borers, rootworms, chinch bugs, and grasshoppers. Snelling and Blanchard (1940) summarized the results of co-operative uniform regional tests of resistance to insect pests on inbreds and hybrids. Painter (1951) listed inbred lines and hybrids that differed in resistance to insects. Other similar data are available in many reports of co-operative tests and state performance trials in the United States.

Infestation Techniques

Painter (1951) discussed methods and problems in breeding for resistance to insects in crop plants. He pointed out that the most useful insect population was one that shows the maximum difference between resistant and susceptible types. This test may be made by using populations in the field or by using cage and laboratory methods. Examples of infestation techniques will be given in the discussion of specific insects.

Reporting Differential Insect Injury

Uniform methods of measuring differences in insect injury benefit all investigators in evaluating strains of maize. In general, numerical rating systems are satisfactory. Rating the material from 1 (showing least injury) to 5 (showing most injury) is a common and desirable procedure. Suggestions for the use of uniform methods were made by Neiswander, Dicke, and Snelling (1949).

Inheritance of Resistance

Resistance and tolerance to insect attacks appear to be quantitative in nature and controlled by a number of genes. Consequently the insect resistance of most double-cross hybrids varies directly with the number of resistant inbred lines involved in their pedigree, as well as with the degree of their resistance.

Nature of Resistance

Snelling (1941) classified plant characteristics affecting insect resistance into 15 categories. Painter (1951) showed by means of a chart how environment, plant, and insect interact to affect resistance to insects. Primary environmental factors included: light, temperature, atmospheric humidity, soil moisture, soil fertility, date of planting, abundance of infestation, and abundance of other hosts. Plant factors were: character of plant covering, lignification or other protective cell structure, growth vigor, growth habit, specialized chemicals, tannin, proteins or alkaloids, *p*H concentration, repair and recovery and destruction of insect parts by growth. Insect factors included: degree of attunement of senses, oviposition, feeding reactions, utilization of food, biological races, and tropistic conditioning from previous host. Insect-plant interactions were: synchronization of development, hypersensitivity of plant cells attacked, toxic materials in insects food, suitability of plant for insect growth and reproduction, and plant resistance to disease carried by insects.

TABLE 25. — IMPORTANT MAIZE INSECTS AND CORN BELT INSECTICIDE RECOMMENDATIONS

Insect	Approximate time of attack	Insecticide		Placement of insecticide	Timing of application
		Name	Lb. of active ingredient per acre		
UNDERGROUND INSECTS					
Cutworms Various spp.	May and June	Dieldrin Toxaphene	0.5 3.0	Base of plant	When damage is first noticeable.
Grape colaspis *Colaspis flavida* (Say.)	June through August	Dieldrin Aldrin Heptachlor	1.0 1.5 1.5	In soil	Within two weeks of planting; work into soil immediately.
Root aphid *Anuraphis maidiradicis* (For.)	Same as grape colaspis	Dieldrin Aldrin Heptachlor	1.0 1.5 1.5	In soil	Within two weeks of planting; work into soil immediately.
Rootworms *Diabrotica* spp.	Same as grape colaspis	Dieldrin Aldrin Heptachlor	1.0 1.5 1.5	In soil	Within two weeks of planting; work into soil immediately.
Seed-corn beetle *Agonoderus lecontei* (Chand.)	Time of germination	Aldrin Dieldrin Heptachlor	According to manufacturer	On seed	At planting time.
Seed-corn maggot *Hylemya cilicrura* (Rond.)	Same as seed-corn beetle	Aldrin Dieldrin Heptachlor	According to manufacturer	On seed	At planting time.
Sod webworm *Crambus* spp.	May and June	DDT	1.5	Over row	At time of initial attack.
White grubs *Phyllophaga* spp.	June through October	Aldrin Heptachlor	3.0 3.0	In soil	Two to three weeks before planting.
Wireworms *Agriotes mancus* (Say.)	Same as grape colaspis	Dieldrin Aldrin Heptachlor	1.0 1.5 1.5	In soil	Within two weeks of planting; work into soil immediately.
STALK, LEAF AND EAR INSECTS					
Armyworm *Pseudaletia unipuncta* (Haworth).	May and June	Dieldrin Toxaphene	0.25 1.75	Over row	At first migration.
Chinch bug *Blissus leucopterus* (Say.)	June to August	Dieldrin	0.5	Base of plant	At start of migration.

TABLE 25. — IMPORTANT MAIZE INSECTS AND CORN BELT INSECTICIDE RECOMMENDATIONS (*concluded*)

Insect	Approximate time of attack	Insecticide		Placement of insecticide	Timing of application
		Name	Lb. of active ingredient per acre		
Earworm *Heliothis armigera* (Hubner)	July and August	DDT	1.5 plus 2 gal. of earworm oil	Ear zone	2 to 4 applications at 3-5 day intervals, starting at 10 % silk.
European corn borer *Pyrausta nubilalis* (Hubner) First generation	June to July	DDT	1.5	Upper third of plant	Two weeks after first egg hatch 10 days before tassel emergence.
Second generation	Mid-August	DDT	1.5	From ear upwards	When eggs are first found hatching in late planted fields.
Flea beetle *Chaetocnema pulicaria* (Melsh)	May and June	DDT Toxaphene Dieldrin	1.5 1.5 0.25	Over row	When damage becomes apparent.
Grasshopper *Melanoplus* and other spp.	June through September	Aldrin Chlordane Dieldrin	0.12 to 0.25 1.0 0.25	Entire plant	As needed; Use twice as much for border sprays.
Japanese beetle *Popillia japonica* (Newm.)	July and August	DDT	1.5	Emerging silks	As needed.
Leaf aphid *Aphids maidis* (Fitch)	July	Malathion Parathion	1.0 0.25	Top of plant	When aphids become prevalent.
STORED GRAIN INSECTS					
Angoumois grain moth *Sitotroga cerealella* (Olivier)	Spray bin walls, ceiling and floor with: DDT - 2.5 % (2 qt. of 25 % emulsifiable concentrate in 4 1/2 gal. of water, or 2 lb. of 50 % wettable powder in 5 gal. of water) or				
Bran bug Various spp.	Methoxychlor (2 qt. of 25 % emulsifiable concentrate in 4 1/2 gal. of water, or 2 lb. of 50 % wettable powder in 5 gal. of water) or Pyrethrin - 0.5 %				
Rice weevil *Sitophilus oryza* (L.)	Fumigate with: Ethylene dichloride - carbon tetrachloride (75 % - 25 %) 4 to 8 gal. per 1,000 bu. of grain, or Carbon disulfide - carbon tetrachloride (20 % - 80 %) 3 to 5 gal. per 1,000 bu. of grain, or Carbon tetrachloride - ethylene dichloride - ethylene dibromide (60 % - 35 % - 5 %) 3 to 5 gal. per 1,000 bu. of grain.				

SOURCE: Petty, H.B., and Steve Moore, 1955 (Modified).

Mechanisms of insect resistance proposed by Painter (1951) included preference, antibiosis, and tolerance. Insects may prefer certain plants for oviposition, shelter, or feeding. Such factors as color, light intensity, or response to chemical stimuli may affect preference or non-preference. European corn borer moths usually deposit their eggs on the tallest or most advanced plants in a neighborhood (Bigger *et al*, 1949).

Antibiosis refers to detrimental effects of the plant on the biology of the insect. Such effects of the plant may result in reduced size, decreased fecundity, and shorter life of the insect. In the European corn borer and the corn earworm, antibiosis appears to be associated with resistance.

The ability of certain plants to grow and produce a good crop in spite of insect infestation is termed tolerance. Contributory factors include the plants' ability to repair or recover from insect damage or better withstand infestation. Vigorous hybrids are usually much more tolerant to chinch bug attack than are the smaller parental inbred lines. Some strains of plants have the ability to replace root systems that have been damaged by underground insects.

Underground Insects

Underground insects normally inhabit the soil while they are injuring the plant. They usually damage the roots or other subterranean parts of the plants. But some insects may feed on or injure parts of the plant above the soil. The more important soil insects include cutworms, grape colaspis, root aphids, rootworms, white grubs and wireworms.

Cutworms (various spp.)

Cutworms girdle young plants, often causing loss of stand. This insect has a plump curled-up appearance when found attacking maize plants. The larvae vary in color from light-glassy to grayish-black or brown. They usually feed at night and sever the plant at or below the surface of the soil. The moths vary from gray to brown. They usually deposit their eggs early in the fall, and the larvae generally develop on forage plants, where they pass the winter.

Apparently very little work has been done to develop strains of maize that are resistant to cutworms. Differences in resistance may be evaluated by recording the percentage of injured or destroyed plants. The insects may be controlled chemically by spraying a band of the row with dieldrin or toxaphene at the rate of 2 pounds per acre. Desirable cultural programs include late-summer or early-fall plowing to eliminate the young larvae.

Grape colaspis (*Colaspis flavida*)

Larvae feeding on the roots of young plants often reduce stands, cause plants to vary in height, and give a red coloration to the plants. Symptoms of colaspis attack are similar to those caused by phosphate deficiency. A considerable amount of damage often occurs to plants growing on relatively poor soil that has been previously cropped to red clover, lespedeza, mammoth clover, soybeans, or timothy.

Maize strains may be rated for differences in resistance from 1 (showing least injury) to 5 (showing most severe injury). Applying aldrin, heptachlor, or dieldrin to the soil at planting time is a recommended control practice. Avoiding the planting of maize on spring-plowed clover or timothy sod is a desirable cultural measure of control.

Root aphids (*Anuraphis maidi-radicis*)

Root aphids cluster on the roots of maize plants. They suck the sap, causing the plants to be dwarfed and stunted. The presence of the root aphid is suggested by numerous ant hills around the plants.

Differences in resistance of breeding material may be recorded on the basis of grades, grade 1 indicating the least stunting or dwarfing and 5 the most severe damage. Rotating crops and applying chlordane to the soil at the rate of one pound per acre are recommended control measures.

Rootworms (*Diabrotica spp.*)

Rootworms often reduce stands, slow down growth, and even cause dwarfing of plants. The larvae feed at the crown of the young plants and may kill the terminal bud or cause tillering. Infestation of older plants often damages the roots, causing lack of standability and decreased yields. Adults feeding on the silks may interfere with pollination and fertilization.

Larvae of the northern corn rootworm (*Diabrotica longicornis*) are slender, about $^{2}/_{5}$ inch long, and white to pale yellow. Adults are about $^{1}/_{5}$ inch long and pale green.

Southern corn rootworm (*D. undecimpunctata howardi*) larvae are slender, about $^{1}/_{2}$ inch long, and white to yellowish. Adults are about $^{1}/_{4}$ inch long and green with black wing spots.

Strains of maize may be resistant to one species of rootworm and susceptible to others. Bigger, Holbert, Flint, and Lang (1938) and Bigger, Snelling, and Blanchard (1941) reported that inbred lines and hybrids differed in resistance and tolerance to the southern corn rootworm. Similar results have been reported by Copper *et al* (1942), Dungan, *et al* (1935, 1938, 1939, 1944, and 1945), Huber (1938), Huber *et al* (1948), Painter (1951), and Dicke (1955). These workers have shown that tolerance is

associated with ability of the plant to regenerate a new root system, resist root rots, and stand well under heavy rootworm infestation. Differences in resistance may be expressed as the percentage of plants root lodged 30 degrees or more from the vertical.

Control includes rotating crops, using resistant strains, and applying insecticides. Applying aldrin, heptachlor, or chlordane to the soil at planting time is a recommended control practice. During pollination adult beetles may be controlled by applying 5 percent DDT dust.

White grubs (Phyllophaga and other spp.)

White grubs often severely injure maize when the crop follows grass sod of one or more years' duration. Larvae feeding on the roots of seedlings often reduce stands and stunt the plants. Mature plants that are damaged may root lodge.

Bigger, Flint, Shropshire and Farrar (1939) reported that white grubs feeding on the roots of single-crosses caused 80 percent of plants of Tr × L317 to lodge compared with 6 percent for 90 × 4211.

Hoegemeyer (1941) reported wide differences in lodging caused by white grubs feeding on the roots of six inbred lines, the 15 all-possible single crosses, and 29 of the 45 all-possible double-cross combinations among them. The inbred lines did not differ significantly in resistance to white grubs. The single crosses and double crosses, however, differed greatly in root injury and root lodging. The most resistant single cross, K41 × K54, had 20 percent of lodged plants compared with 87 percent for K41 × K63. Differences in lodging and root injury caused by grub worms are shown in Figure 73.

Susceptibility to white grub injury may be evaluated by rating the inbreds or hybrids in five classes. Root lodging may be expressed as percentage of plants lodged 30 degrees or more from the vertical. Applying aldrin, heptachlor, or dieldrin to the soil at planting time usually helps to control this insect.

Wireworms (Agriotes mancus Say and other spp.)

Wireworm larvae attack the germinating seed and young seedlings, severely injure the crop and reduce the stand. Damage is usually greatest in the wetter parts of maize fields following sod or cereal grains. Wireworms also feed on the roots of more mature maize and cause plants to die prematurely. The larvae are slender, shiny, buff to reddish-brown worms from ½ to 1½ inches long.

Almost no effort has been devoted specifically to breeding for resistance to this insect. Differential data may be obtained by recording the percentage of plants injured. Short rotations, clean cultivation, fallowing,

FIGURE 73. - *Differential field lodging and root injury caused by grub worms* (Phyllophaga *spp.*).

(Courtesy, R. W Jugenheimer, 1938)

FIGURE 74. - *Some strains of maize are severely injured by chinch bugs* (right) *while other strains survive and produce a satisfactory crop* (left).

and soil drainage give relief from wireworm infestations. Some of the new insecticides also provide effective and practical control. Aldrin, heptachlor, or dieldrin may be applied to the soil at planting time.

Stalk, Leaf and Ear Insects

This group includes the more important insects that attack maize. Insects discussed in this section include armyworms, chinch bugs, earworms, European corn borers, flea beetles, grasshoppers, Japanese beetles, and leaf aphids. Excellent recent reviews have been given by Painter (1951) and Dicke (1955).

Armyworms (Pseudaletia unipuncta)

The larvae of the armyworm may originate in the maize field or migrate from adjacent fields of cereals or other grasses. Infestation begins on the tender part of the leaves. Severe feeding may leave the plants stripped of foliage to the mid-rib.

Relative resistance of breeding material may be evaluated by rating injury to the foliage in five grades.

Cultural practices should attempt to eliminate over-wintering larvae by exposing infested stubble on the soil surface to freezing temperatures. Chemical control includes spraying the insects with dieldrin or toxaphene.

Chinch bugs (Blissus leucopterus)

Chinch bugs have piercing mouth parts and feed by sucking the sap from the plants. Painter (1928) found that they obtained food from the phloem and that feeding clogged the conductive tissue of the plant.

The chinch bug produces reddish eggs about $^1/_{32}$ inch long. Nymphs change from light red to almost black. Adult bugs are about $^1/_6$ inch long and have black bodies with white wings.

Outbreaks of chinch bugs depend primarily on above-normal temperatures and below-normal rainfall in the spring and summer. Usually the nymphs and adults of the first brood migrate on foot to maize from adjacent fields of small grains. Barley is an excellent source of infestation. Heavy attacks cause the young succulent plants to wither rapidly.

The second brood develops from eggs deposited in maize fields. These infestations often stunt the plants and even cause them to die prematurely. In the more susceptible older plants (Figure 74), the stalks break, yields are reduced, and the grain is poor in quality.

Differences in resistance of open-pollinated varieties to chinch bugs were reported by Flint (1921); Burlison and Flint (1923); Flint and Hack-

leman (1923); Painter (1928); Holbert, Flint, and Bigger (1934); and Holbert, Flint, Bigger, and Dungan (1935). Experimental work in Illinois showed that Black Hawk, Golden Beauty, Champion White Pearl and Mohawk were the more resistant open-pollinated varieties.

Holbert *et al* (1934, 1935) found that inbred lines of maize differed in resistance and susceptibility to chinch bugs. In some inbred lines, resistance was a dominant trait, while in others susceptibility appeared to be dominant.

Painter, Snelling, and Brunson (1935) studied hybrid vigor and other factors in relation to chinch bug resistance in maize. They found that vigorous F_1 hybrids were much more resistant to both first- and second-brood attacks than were their parental inbred lines. Resistance appeared to be due to:

1. inherited specific resistance to chinch bugs;
2. tolerance to or escape from injury associated with heterotic vigor.

These workers reported little correlation between the behavior of the same inbred or hybrid at Manhattan, Kansas, and Lawton, Oklahoma. Painter (1951) believed that this discrepancy in results at the two stations might have been due to differences in:

1. adaptation, size, and age of plants; or
2. type and duration of insect attack.

Relative resistance of maize strains may be measured as the percentage of plants standing after a heavy infestation and as ratio of total yield to yield of sound grain. Strains may be rated in classes ranging from 1 (showing least injury) to 5 (showing most injury). Since early maturing strains usually show more severe damage than the later more vigorous strains, comparisons should be made between strains of similar maturity. Data on damage from second-generation broods may be supplemented by records on yield and standability. Reliable observations can be made only where the infestation is uniformly distributed.

Chinch bugs may be controlled by spraying edges of the field with dieldrin at the rate of ½ pound per acre when migration to maize begins (Decker, Bigger, and Weiman, 1953, and Bigger and Petty, 1953). These barriers remain effective for 7 to 14 days. Substituting legumes for cereals in areas of heavy infestation is a desirable cultural practice. Migrations may be reduced by barriers treated with coal-tar creosote and dusts containing DDT or a dinitro compound.

Earworms (*Heliothis armigera*)

The corn earworm attacks the maize crop throughout most of the world. Types of injury include direct damage to the ear and breaking of the stalk due to the introduction of disease organisms. This insect

formerly prevented profitable production of sweet corn in the southern part of the United States. It still causes varying amounts of damage to most types of maize throughout the growing areas.

The earworm goes through four stages of development: egg, worm, pupa, and moth. The moths are light olive green to buff. The female moth lays as many as 2,000 eggs, which hatch in two to five days. Early generations of the larvae feed in the whorl of the young maize plants. Some of the later generations lay their eggs on fresh silks shortly after pollination.

The newly hatched larvae are light green with small, dark hairs. They feed from the silks into the tip of the ear toward the shank. The larvae are cannibalistic, and usually only one full-grown worm is found on each ear. The older larvae range from red and brown to green. When

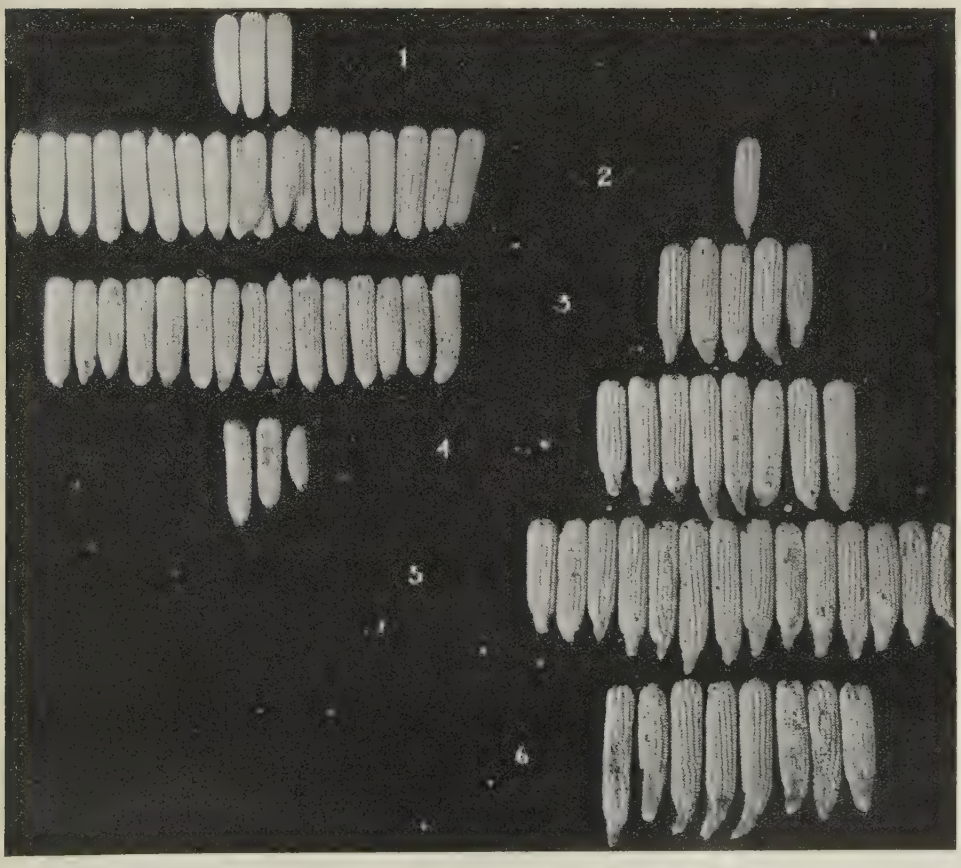


FIGURE 75. - *Contrasts in resistance* (left: *K126* × *K151*) *and susceptibility* (right: *K201* × *38-11*) *of two single crosses to natural infestation of earworm* (Heliothis armigera *Hubner*). *The numbers indicate the class of injury.*

(Courtesy, R. W. Jugenheimer, 1938)

fully grown, they leave the ear, go into the ground, and become pupae. Development from egg to adult takes about 30 days.

Breeding for resistance to earworms in maize was reviewed by Painter (1951), Eckhardt and Douglas (1955), and Dicke (1955). Many other workers have observed differences among inbred lines in resistance to earworm. The relative resistance of a large number of inbred lines is presented in Tables III and IV in the Appendix. Jugenheimer and Painter evaluated hundreds of inbreds and hybrids in Kansas during 1938-1943. Similar data have been presented by Painter and Brunson (1940); Blanchard, Bigger, and Snelling (1941); Bigger and Snelling (1942); Richey (1944); and Dicke and Jenkins (1945), as well as in other publications of the North-Central Maize Workers of the United States.

Blanchard and his associates (1942) reported on artificial infestation methods. This procedure consists of putting one or more larvae on the silks of each ear shoot at the time of pollination. Relative resistance is measured by the degree of damage to the kernels on the ear. Some investigators classify earworm damage into these six groupings:

Class

0: no infestation;
1: silk and tip damage up to 5 kernels;
2: damage to 6 to 15 kernels;
3: damage to 16 to 25 kernels;
4: damage to 26 to 40 kernels;
5: damage to more than 40 kernels.

Neiswander, Dicke, and Snelling (1949) suggest that damage caused by the earworm and by diseases induced by earworm infestation should be considered in assigning class ratings. Figure 75 shows contrasts in resistance and susceptibility of two single crosses to natural infestation of earworm.

Some workers evaluate differences in resistance by using only three classes:

1. most ears penetrated less than 1 inch from tip;
2. most ears penetrated 1 to 2 inches from tip;
3. most ears penetrated more than 2 inches from tip.

Other workers express differences in resistance as percentage of ears with a definite amount of earworm damage. Such data by Blanchard, Bigger, and Snelling (1941) are shown in Table 26. The percentage of infested ears showing more than Class 2 damage ranged from 7 to 70 percent for the inbred lines, but only 3 to 11 percent for the single crosses. This table illustrates the effect of heterosis on damage.

Collins and Kempton (1917) reported using three measures of earworm infestation:

1. amount of damage;
2. number of larvae;
3. damage per larva.

TABLE 26. — EARWORM INJURY SHOWN BY ALL-POSSIBLE SINGLE-CROSS HYBRIDS OF SIX YELLOW INBRED LINES OF MAIZE, MCCLURE, ILLINOIS, TWO-YEAR AVERAGE, 1938-1939

Inbred line	Percentage of infested ears showing more than Class 2 damage					
	Ia. L317	Ind. 38-11	ILL. Hy	U.S. 540	ILL. R4	Ind. WF9
Ia. L317	—	17.2	10.1	2.6	1.4	4.9
Ind. 38-11	17.2	—	20.9	4.4	5.3	7.6
ILL. Hy.	10.1	20.9	—	3.7	5.7	4.8
U.S. 540	2.6	4.4	3.7	—	2.4	3.4
ILL. R4	1.4	5.3	5.7	2.4	—	3.2
Ind. WF9	4.9	7.6	4.8	3.4	3.2	—
Average of crosses	7.2	11.1	9.0	3.3	3.6	4.8
Inbred line	16.2	70.3	33.1	8.1	7.0	8.4

SOURCE: Blanchard, Bigger, and Snelling, 1941.

Highly significant interprogeny correlations of these three measures of earworm infestation were obtained with:

1. prolongation of husk beyond the ear;
2. length of husk.

Kyle (1918) also reported that long, tight husks reduced the possibility of damage. In the United States, many workers have found that the later maturing material tends to be more resistant than earlier material.

After reviewing the literature, Painter and Brunson (1940) listed the following characteristics as the chief mechanisms affecting the resistance of maize to earworm:

1. length of husk;
2. cannibalism of larvae;
3. tightness of husks;
4. number of husk leaves;
5. number of husk layers;
6. male florets at tip of ear;
7. synchronization of time of silking and peak of oviposition;
8. hairiness of plant;
9. length of silking period;
10. number of ears per plant;
11. total leaf area available for oviposition;
12. attractiveness of plant for oviposition;
13. value of plant as food for larvae.

Eckhardt and Douglas (1955) discussed the nature of resistance to earworm. They pointed out that some of the hybrids in the southern

part of the United States, where earworm damage has been greatest, have long, tight husks. Other possible resistance factors include:

1. preferential egg-laying;
2. eggs sticking on certain silks better than others;
3. differences in palatability of silks, cob, or grain;
4. lack of elements essential for growth.

Jugenheimer reported highly significant correlations between resistance to corn earworms and days to half pollen, days to half silk, days to maturity, ear height, ears per plant, *H. turcicum*, smutted plants, kernel rot, and leaf aphids (Table 10, page 100).

Control of the earworm includes using resistant strains and spraying the silks with DDT in a mineral oil emulsion. Gannon, Luckmann, and Petty (1955) state that the most effective earworm insecticide is DDT applied at the rate of 1½ pounds per acre. To spray an acre, 3 quarts of 25 percent DDT emulsion concentrate should be mixed with 2½ gallons of a highly refined mineral-type oil, and enough water should be added to make 25 gallons of spray. They recommend applying this spray with a high-clearance, self-propelled sprayer that can maintain 50 to 150 pounds of pressure with all nozzles in use.

The spray solution must be agitated constantly. The first application should be made when about 20 percent of the ears in the field show fresh silks. The crop must then be sprayed every 3 to 5 days thereafter in order to keep the silks covered with insecticide. The number of applications will depend on length and intensity of egg-laying, uniformity of silking, and value of the crop.

European corn borer (*Pyrausta nubilalis*)

The European corn borer is often very destructive to the corn crop. The first-brood larvae cause a considerable amount of leaf injury. Feeding points vary in size from a small pin point to larger areas. Frequently the larger larvae attack the leaf sheath and midrib and then burrow into the stalk. The second brood, however, does more damage than the first. Decreased yield, lodged plants, ear droppage, and poor grain quality are the results of second-brood infestation. Damage from corn borer in the United States was estimated at U.S.$350 million in 1949 and U.S.$261 million in 1954.

Borer damage is primarily of three types:

1. leaf feeding, which destroys the leaf surface, breaks the midribs, and reduces yields;

2. stalk tunneling, which destroys food channels, weakens the plant, and descreases yields; stalk rot organisms enter these tunneled areas, weaken the stalk and increase stalk lodging, making the crop more expensive and difficult to harvest;
3. shank infestation, wich causes ear droppage, ear damage; preyents the ears from developing properly.

The borer passes the winter as a brownish or pinkish larva in stalks or other plant debris. In the Corn Belt of the United States, the larva changes to a brown pupa about mid-May. The yellowish or brownish moth emerges any time from late May to early July.

The first-brood female begins to lay eggs soon after emerging and mating. She deposits the eggs in irregular white clusters about $^1/_4$ inch wide, usually on the underside of maize leaves. Each female moth lays from 400 to 500 eggs in clusters of 15 to 25. The eggs hatch in five to seven days, and the young larvae emerge.

The larva is the destructive stage of the European corn borer (Figure 76). The young larvae of the first brood feed in the whorl, leaf sheath, and midrib of the plant and may cause yields to be reduced. The older first-brood larvae do the most damage from late July to late August, after they bore into the stalks and ears. The borer larvae go through five stages of growth. The full-grown larvae are about $^3/_4$ inch long.

Eggs of the second brood, coming from moths developed in the first brood, are laid between late July and early September. The larvae appear from early

FIGURE 76. - *Broken leaves and castings show that European corn borers have been at work here. Stalk boring and leaf breakage lead to heavy losses in grain yield. This damage was done by first-generation borers on maize planted too early.*

(Courtesy, J. H. Bigger *et al.*, 1949)

August to late October. The heaviest damage of this brood is done to the maturing crop. Tunneling of the larvae into the plant often increases infection and damage from stalk-rotting organisms.

Many workers have shown that inbred lines and hybrids differ in resistance and tolerance to the corn borer. The relative resistance of many inbred lines is shown in Tables III and IV in the Appendix. Plant characters associated with European corn borer are shown in Table 10, page 100.

Resistance and tolerance of maize strains is complex. The moths tend to deposit their eggs on the tallest or most advanced plants in the neighborhood (Figure 77). The larvae from eggs laid by early-season moths survive better on the taller, usually earlier maize, than on the shorter, later maturing maize. They are most likely to live when they hatch on plants that are almost ready to tassel.

Patch (1943) and others have demonstrated differences in larval survival and growth rate. Plants of some inbreds and hybrids seem not to attract the moths. Even though the plants are in good physical condition, the moths lay few eggs on them. Fewer larvae also burrow into the plants of some inbreds and hybrids than into others.

Certain strains show different degrees of tolerance to borer damage. Some strains of maize have the ability to grow and produce a good crop in spite of considerable numbers of borers. The more tolerant strains stand well and produce satisfactory grain yields in spite of borer infestation.

Infestation techniques have been developed to aid in breeding for resistance and tolerance (Patch and Pierce, 1933). For this procedure, the caged moths lay their eggs on sheets of paper. Each egg mass usually contains about 20 eggs. The egg masses on these sheets are cut into small discs by machine, and a pin is stuck through these discs. The plants are infested by dropping from two to four of these discs into the whorl of individual plants when they are about one meter high and before the tassels appear (Figure 78). Illinois inbred lines, R71, R109B, R113,

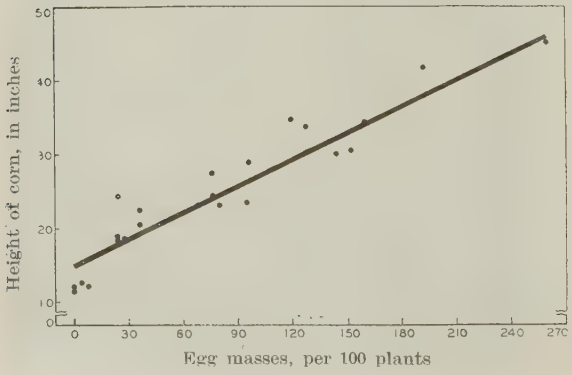


FIGURE 77. - *When given a choice, moths of the European corn borer select the tallest or the most advanced maize in a neighborhood on which to lay their eggs.*

(Courtesy, J. H. Bigger *et al.*, 1949)

FIGURE 78. - *Infestation technique for evaluating resistance and tolerance to European corn borer* (Pyrausta nubilalis).

and R168, were developed by this infestation procedure, and were released in 1956 to seedsmen because of their resistance to European corn borers.

Relative damage of plants by the larvae is a measure of their resistance. Ratings can be made about three weeks after the eggs hatch. Separate ratings may be made for oviposition, damage to leaves, leaf sheath, and stalk burrowing. Differences in evaluation can be made by using grades. Most investigators use 10 grades for this purpose. Tolerance is also reflected between strains of maize in differences in broken stalks, dropped ears, and decreased grain yields.

Control of the European corn borer includes four measures:

1. use of resistant and tolerant hybrids adapted to the growing season;
2. proper cultural practices;
3. use of insecticides:
4. biological control.

Some of the overwintering borers may be destroyed by carefully plowing under all stalks and other plant refuse before the moths emerge in the spring. When soil conditions permit, plant debris should be buried at least 6 inches deep in order that later cultivations will not bring it to the surface. Fall plowing should be done where soil blowing and erosion is not a problem. Chopping, husking, or shredding machines will also kill many borers.

In order to obtain highest grain yields, the crop should be planted at the usual time. Early-planted maize is usually severely infested by first-brood borers. The late-planted crop is likely to be heavily infested late in the season by second-brood borers. The result is a considerable amount of stalk breakage and ear droppage.

An insecticide may be the most practical way to prevent serious damage in heavily infested maize. Number and time of treatments will depend on the severity of infestation. A properly timed treatment against first-brood borers often provides adequate control. A single treatment is usually applied when three fourths of the plants show evidence of recent feeding in the whorl, or 10 to 14 days after the first eggs hatch if there are still 50 or more egg masses per 100 plants.

The United States Department of Agriculture's *Farmers' Bulletin 2084* (1955d) recommends the following control measures:

Sprays: Use DDT at the rate of 1½ pounds per acre. With ground equipment apply an emulsifiable concentrate in 5 to 50 gallons or a wettable powder in 15 or more gallons of water per acre. The emulsion is commonly applied at the rate of 10 gallons per acre. The quantity of concentrate or wettable powder will depend on its concentration, as given on the label. With an airplane, apply an emulsifiable concentrate in 2 to 5 gallons of water per acre.

Dusts: Use DDT at the rate of 2 pounds, or ryania at the rate of 12 to 16 pounds per acre. A 5- or 10-percent DDT dust or a 40-percent ryania dust can be obtained ready-mixed.

In general, applying insecticides with ground equipment has been more effective than applying with airplanes, and sprays have given better control than dusts under most conditions.

DDT is moderately poisonous to warm-blooded animals. Therefore, precautions should be taken in feeding forage that has recently been treated with this insecticide.

A number of natural enemies and imported parasites have been released over most of the areas that are heavily infested with borers in the United States in an effort to obtain biological control of the insect.

Flea beetle (*Chaetocnema pulicaria*)

The presence of the flea beetle is indicated by short, narrow feeding lesions parallel to the veins on the leaves. These lesions are about $^1/_4$ inch long. Under heavy infestation the foliage of young plants appears to be withered and bleached. The adult flea beetle is the most injurious form. It is oblong, black or dark green, and about $^1/_{16}$ inch long. The flea beetle is responsible for both the overwintering and transmission of Stewart's disease, which may cause wilting and premature dying of the leaves.

Inbred lines of maize differ considerably in their resistance to flea beetles (Table IV in the Appendix). Inbred lines and hybrids may be

evaluated for resistance in the young plant stage and again at the roasting-ear stage. Differences may be recorded in five groups, grade 1 representing the least injury and grade 5 the most.

Stewart's disease can be partly controlled by using resistant strains. Spraying or dusting the plants with DDT, toxaphene, or dieldrin when damage is apparent will help to control the disease by killing the flea beetle.

Grasshoppers (Melanoplus spp.)

Grasshoppers and locusts cause heavy damage to crop and range plants in many of the drier areas of the world. Maize plants are subject to attack at any stage of growth. Under light infestations, grasshopper nymphs and adults feed primarily on the leaves. They also feed on the silks and tips of ears and thus interfere with pollination. Under heavy infestations, grasshoppers may eat all of the leaf surface and even the entire plant. A useful, up-to-date bulletin on grasshoppers was prepared by Parker (1954).

Resistance to grasshoppers and locusts in maize has been reviewed by Painter (1951). Brunson and Painter (1938) reported differences in feeding of grasshoppers on maize and sorghums. Differences in defoliation of maize ranged from 7 to 31 percent among a group of open-pollinated varieties and from 4 to 60 percent among hybrids.

FIGURE 79. - *Differences in resistance of maize hybrids to grasshoppers. The resistant hybrid* (left) *is Kansas 2234, while the susceptible strain* (right) *is U.S. 35. Kansas 2234, a white hybrid, also is resistant to drought and has an outstanding record for yield and other agronomic characters.*

(Courtesy, R. W. Jugenheimer, 1941)

TABLE 27. — FREQUENCY DISTRIBUTION OF 89 HYBRIDS AND VARIETIES TO GRASSHOPPER DAMAGE, MANHATTAN, KANSAS, 1941

Percent of leaf surface removed by grasshoppers								
1 - 10.9	11.0 - 20.9	21.0 - 30.9	31.0 - 40.9	41.0 - 50.9	51.0 - 60.9	61.0 - 70.9	71 - 80	81 - 90
K 1501	K 2182	K 2086	F 583S	Kelly 200	U.S. 44	F 53	U.S. 13	
K 2234	K 2232	Reid-Mid.	H. G.	F 103	Jew. 6	K-K 77A	U.S. 35	
	P of S	K 17	K 2173	McC.123M	Pio.332	Pf. 380		
	K 1585	Mangle. 1001	F 150	KIH 26	Mid. (C)	KIH 38		
		Jew. 12	Kelly 374	K 1104	Pio. 333	K-K 77		
		Carl. C33	Pio. 330	Mc118M	DeK. 816	Steck. S770		
		K-K 88A	Pio. 1356A	Mo. 8	Pf. 160	Pf. 5892		
		Greene	K 1466	Pio. 300	Iowa 939	DeK. 827		
		F 148	Stand. 813	Steck. 860	K 1638			
		F 149	F 244	H.C. 840				
		Stand. 913	Greene	Steck. 523				
		Nat. 134	K 3	ILL. 200				
		K 12	Mo. 47	ILL. 960				
		I'th.29A	K 11	Jew. 11				
		KIH 41	Pio. 334	K 12				
		K 2181	K 1412	K 2216				
		Pio.307	Richey 1002	KIH 96				
		K 1624	K 20	K 1549				
		K 3	RYD					
		I'th.TX1	F 147					
		F 135	Mid. (A)					
			F 46					
			F 88					
			K 2015					
No. 2	4	21	25	18	9	8	2	0
Pct. 2.2	4.5	23.6	28.1	20.2	10.1	9.0	2.2	0

SOURCE: Jugenheimer, 1941.

FIGURE 80. - *Relative resistance to grasshoppers of hybrids may be determined in the seedling stage under controlled conditions in cages. These hybrids are:* (A) *K2234*, (B) *K2182*, (C) *DeKalb 816, and* (D) *U.S. 35. Mature plants of K2234 and U.S. 35 are shown in Figure 79.*

(Courtesy, R. W. Jugenheimer, 1941)

Jugenheimer and Painter reported extreme differences among inbred lines and hybrids in resistance to grasshoppers in Kansas (Jugenheimer, 1941; Jenkins, 1942). The frequency distribution of 89 strains to grasshopper damage is shown in Table 27. Kansas hybrids K2234, K2232, and K1585 had less than 21 percent of the leaf surface removed compared with 71 to 80 percent for U.S.13 and U.S.35 (Jugenheimer, 1941). The Kansas hybrids, were developed under conditions of heavy grasshopper infestation and were injured considerably less than varieties like U.S.13 and U.S.35, which were developed in an area that was relatively free from invasions of grasshoppers. Extreme differences between K2234 and U.S. 35 in damage from grasshoppers are shown in Figure 79.

The amount of leaf surface that is destroyed may be evaluated by using five grades. Strains usually are rated from 1 (least injury) to 5 (most severe injury). Such ratings are most accurate when the infestation develops uniformly from the ends of the plots. All strains should be of reasonably similar maturity.

Unfortunately, the degree of insect infestation in field plots cannot be controlled. Jugenheimer (1941) and Neuschwander (1946) reported

that the relative resistance to grasshoppers of hybrids could be determined in the seedling stage under controlled conditions in cages (Figure 80). Resistant hybrids K2234, K2232, and K1585 developed by the author, have been released for commercial production.

Marchioni (1940) also used cages to study resistance of maize to grasshoppers. Horovitz and Marchioni (1942) found that resistance apparently was not associated with leaf hairiness, anthocyanin pigment, yellow endosperm, or chemical composition of the plant. Resistance to defoliation by grasshoppers and locusts appeared to be controlled by genetic factors. The relative resistance of hybrids appears to depend on the number and degree of resistance of the parental inbred lines.

Insecticides are the major weapon for controlling grasshoppers, although the use of resistant hybrids and slight modifications in tillage and seeding practices are also desirable procedures. The entire plant may be sprayed with the following amounts of active ingredients per acre: aldrin, 2 to 4 ounces; chlordane, 1 pound; dieldrin, 4 ounces; heptachlor, 3 to 4 ounces; or toxaphene, 1 to 1½ pounds.

Japanese beetle (*Popillia japonica*)

Adult Japanese beetles feeding on the silks of the maize plant cause incomplete pollination and scatter-grain setting of seed. Larvae sometimes feed on the roots and leaves of the plant. The adult beetle is about ½ inch long, oval, and has a metallic-green body and brownish wings.

Coon (1951) reported differences in varietal resistance to this insect. Factors affecting extent of injury include date and rate of silking, beetle population, abundance and duration of pollen flow, and rapidity of pollen grain germination. Differential ratings may be taken at intervals of a week or ten days. These notes, which should include the degree of silk clipping, may be recorded under five grades. Foliage sprays of dieldrin or DDT dust provide protection against beetle injury.

Leaf aphids (*Aphids maidis*)

The maize leaf aphid occurs in temperate and tropical areas of the world. The number of generations each year depends primarily on temperature. In the Corn Belt of the United States, the insect usually appears in the maize field about midsummer and may continue until frost. Large colonies may occur on the tassels, leaves, and ear shoots. Usually they appear first in the whorl and on the upper leaves, but they breed abundantly on the tassel when it appears. Heavy infestations usually reduce pollen shedding. Sucking of sap from the plants and partial prevention of pollination may reduce grain yields.

McColloch (1921) reported differences in resistance among open-pollinated varieties. Susceptibility appeared to be partly associated with late maturity. Many workers have reported differences in resistance among inbred lines and hybrids. These results were reviewed by Painter (1951). Differences in resistance among a large group of inbred lines are reported in Tables III and IV in the Appendix.

Individual inbred lines differ greatly in their prepotency in transmitting aphid resistance or susceptibility to their hybrids. The genetics of resistance appears to be complex and due to many genes.

Huber and Stringfield (1942) reported that susceptibility to aphids was correlated with damage by the European corn borer. They pointed out that the preliminary classification of breeding material to the corn borer might be based on aphid population.

Jugenheimer (Table 10, page 100) found significant correlations between leaf aphids and days to half pollen, days to half silk, days to maturity, plant height, ear height, *H. turcicum*, *H. maydis*, Gibberella stalk rot, European corn borer leaf feeding, corn ear worm, and weight of seed.

Haber and Gaessler (1942) studied the nature of resistance of maize to leaf aphids. They found no relation between susceptibility to aphids and sugar content of the host plant. Coon (1948) reported that inbred lines having tassels exposed quickly and completely from the leaves tended to have the lowest aphid populations. Coon, Miller and Aurand (1948) found some association between degree of aphid infestation and carotene content of maize grain.

Most workers evaluate their breeding material on the percentage of stalks with aphid colonies and also on size of the colonies.

Stored Grain Insects

Cotton (1949) discussed the control of insects under storage conditions. He pointed out that the need to protect seed from insect attack is of great importance to the seedsman faced with the problem of providing viable seed. The germ of the seed, with its high food value, is especially attractive to certain insects. Destruction of the germ is often the first injury resulting from attack by the India meal moth, almond moth, cadelle, or flat grain beetle. The rice weevil, Angoumois grain moth, granary weevil, and lesser grain borer usually damage the grain as a whole. The red flour beetle and saw-toothed grain beetle feed chiefly on broken kernels.

High relative humidity and high temperature hasten the life processes of seed and shorten the period of viability. These same conditions also speed up the development of seed-infesting insects. Most stored grain insects do not lay eggs at temperatures below 60° F. The moisture content of the grain also affects insect infestation.

Control of stored grain insects involves sanitation, fumigation, and use of various dusts and sprays. The bin walls, ceiling, and floor of storage facilities may be sprayed with DDT, methoxychlor, or pyrethrin. Storage facilities may be fumigated as needed with ethylene dichloride plus carbon tetrachloride, carbon dilsulfide plus carbon tetrachloride, or carbon tetrachloride plus ethylene dichloride plus ethylene dibromide. Amounts of insecticide to use are shown in Table 25, pages 202 and 203.

Angoumois grain moths (Sitotroga cerealella)

The Angoumois grain moth causes heavy losses of grain. This insect infests the grain in storage and in the field in the warmer climates. In the temperate zone and the tropics, the grain becomes infested in the field, and damage continues in the stored grain.

Cartwright (1930) reported an inverse relationship between insect damage and husk extension beyond the ear. Blanchard and Snelling (1942) reported damage from Angoumois grain moths and rice weevils ranging from 1.2 percent to 14.9 percent among a group of 20 white single crosses in two locations.

Rice weevil (Sitophilus oryza L.)

The adult rice weevils eat small cavities in the grain into which they deposit their eggs. The larvae feed on both germ and endosperm. The weevil is dark reddish-brown, about $^1/_6$ inch long and has two light spots on each wing cover. The larva is a white, thick-bodied grub.

Eden (1952) reported that long tight husks and kernel hardness were associated with resistance to the rice weevil. Hinds (1914) reported that weevil resistance was associated with length and thickness of the husk covering on the mature ear. Early-maturing varieties tended to be damaged more severely than later maturing strains. Kyle (1918) suggested possibilities for developing strains of maize that would be resistant to the rice weevil. Blanchard and Snelling (1942) also reported differences among inbred lines and hybrids. Eckhardt, Douglas, and Hamner (1946) reported similar results.

Maize breeders in the southern part of the United States use uniform methods for recording differences in resistance to rice weevil infestation (Jenkins, 1947b). These workers record the number of infested and noninfested ears in each plot and then grade the infested ears on a bulk basis according to three classifications:

1. 5 percent or less of the kernels showing weevil emergence holes;
2. 5 percent to 25 percent of the kernels showing emergence holes;
3. more than 25 percent of the kernels showing emergence holes.

15. DESIRABLE SEED AND POLLEN PARENTS

Many desirable traits must be incorporated into maize hybrids. Hybrids must produce high yields of excellent quality grain for the farmer. They must also be practical for the seedsman to grow for seed. Seed and pollen parents differ greatly in their desirability. Better seed parents may materially reduce the cost of production. Use of cytoplasmic male sterility and genic pollen restorers is lessening and eventually may almost eliminate most of the need for manually detasseling hybrid seed production fields.

High Yields of Salable Seed

Desirable seed parents should be single-stalked to lessen the task of detasseling; should have strong stalks, roots, and ear shanks; should be adapted to machine harvesting; and should produce high yields of salable seed. Proper husk cover, popular size and shape of seed, high germination, longevity of seed, and strong seedling vigor are other desirable traits.

More than 500,000 acres of land in the United States are used each year to produce hybrid seed. Therefore, every extra bushel of salable

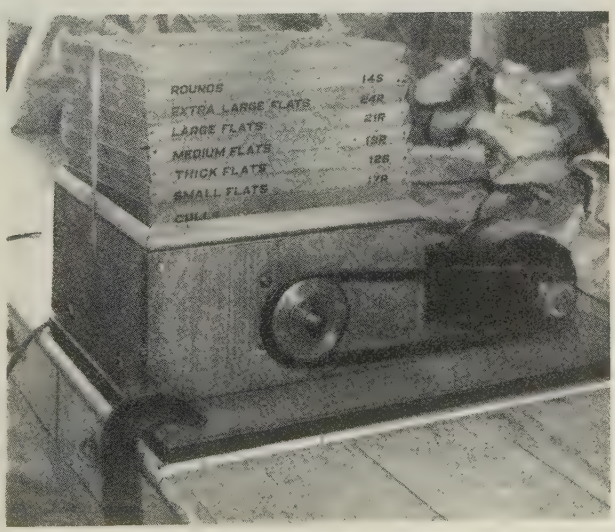
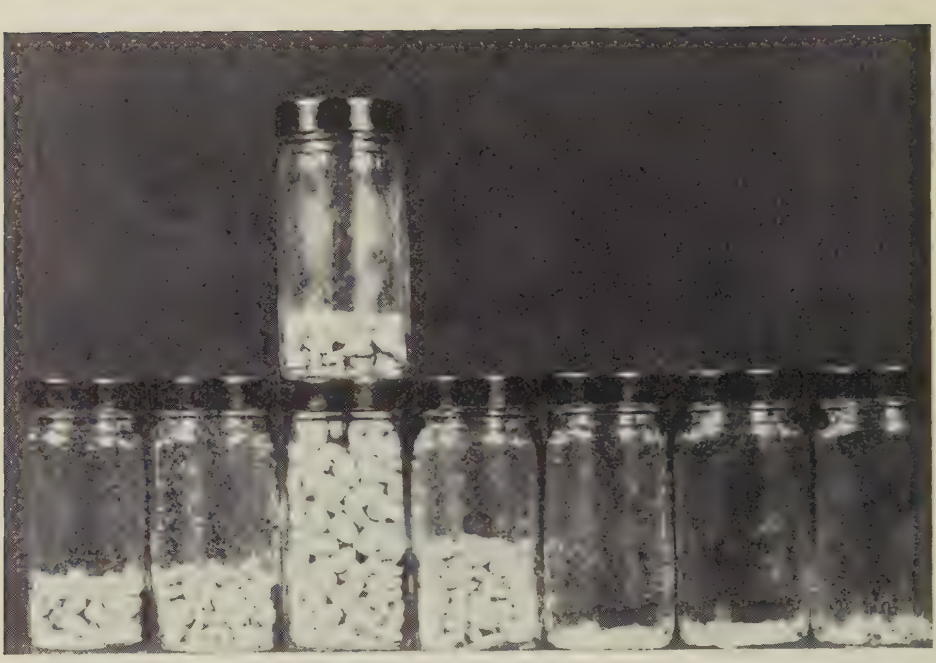
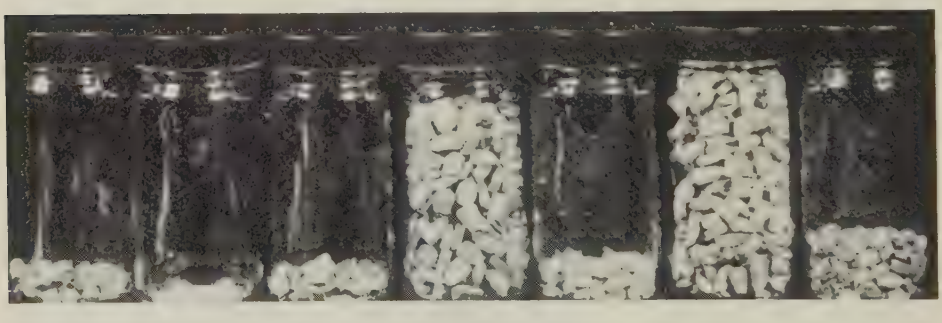


FIGURE 81. - *This experimental machine efficiently separates 500-gram samples of seed into commercial grades. The designations on the screens refer to the size and shape of the opening—14S, for example, means a slotted opening $^{14}/_{64}$ inch across; 24R means a round opening $^{24}/_{64}$ inch in diameter.*

(Courtesy, R. W. Jugenheimer)



Rounds	Extra large flats	Large flats	Medium flats	Thick flats	Small flats	Culls
12 %	12 %	53 %	19 %	1 %	2 %	1 %



Rounds	Extra large flats	Large flats	Medium flats	Thick flats	Small flats	Culls
4 %	0 %	5 %	34 %	6 %	40 %	11 %

FIGURE 82. - *Sixty-five percent of the seed of single cross K201 × 38-11 (shown at top) graded large flat and extra large flat, while only 5 percent of the single cross K4 × 38-11 were in the same grades. The K4 × 38-11 cross had a much higher proportion of small flats and culls than the K201 × 38-11 cross.*

(Courtesy, R. W. Jugenheimer)

seed produced per acre represents at least an additional five million dollars to the hybrid seed industry.

Jugenheimer (1949f) made tests to locate better grading seed parents. An experimental machine efficiently separates 500-gram samples of seed into commercial grades (Figure 81). Operated for one minute per sample, it separates each lot into rounds, extra large flats, large flats, medium flats, thick flats, small flats, and cull grain. Designations on the screens indicate the size and shape of opening: 14S, for example, means a slotted opening $^{14}/_{64}$ inch across; 24R, a round opening $^{24}/_{64}$ inch in diameter.

In these tests single-cross parents were found to differ greatly. For example, 65 percent of the seed of K201 x 38-11 graded large flat or extra-large flat compared with only 5 percent for K4 × 38-11 (Figure 82). Forty percent of K4 × 38-11 seed graded small flat compared with only 2 percent for K201 × 38-11. Also K201 × 38-11 had only 1 percent of cull grade, while K4 × 38-11 had 11 percent.

Seed size is a hereditary trait. The prepotency of inbred lines to contribute differences in size and shape of seed to single crosses is shown in Table 28.

Cytoplasmic Male Sterility to Eliminate Detasseling

Use of cytoplasmic male sterility may be used to reduce the amount of detasseling needed to produce hybrid seed. Introduction of cytoplasmic sterility into a breeding program, however, is costly, time-consuming, and tends to delay progress. There is little reason, therefore, in introducing cytoplasmic sterility into inbred lines and hybrids unless it is certain that hybrid seed involving them will be produced in considerable quantities for several years.

Jugenheimer (1952a) pointed out advantages and possibilities versus disadvantages and problems of utilizing male sterility to eliminate detasseling in the production of hybrid maize seed.

Advantages and possibilities

Detasseling the seed parent plants in 500,000 acres of maize presents a tremendous personnel problem. At present the seed industry must find, train, and carefully supervise thousands of temporary workers. Judicious use of cytoplasmic male sterility should lessen the need for most of this work and alleviate some of the problems hybrid seed producers are now experiencing.

The hybrid industry probably spends 10 million dollars each year for detasseling seed fields. At present detasseling costs probably average about $20.00 per acre. Such costs may be materially reduced by the intelligent use of male sterility.

TABLE 28. — MEAN PERCENTAGES OF SEED IN VARIOUS GRADES OF INBRED LINES IN ALL POSSIBLE SINGLE-CROSS COMBINATIONS, ILLINOIS

Aurora, 1946

Grade	Wisc. W22	Ohio Oh51A	Wisc. W8	ILL. M14	Iowa I.205	Wisc. W32	Ohio Oh28	Ind. WF9	ILL. A	Nebr. N6	Mean
Round	8	9	10	9	11	11	10	9	11	11	10
Extra large flat	0	2	1	1	0	0	0	0	0	1	0
Large flat	6	24	14	12	8	5	6	11	6	18	11
Medium	27	37	32	29	26	23	24	36	25	36	30
Thick flat	10	7	9	8	11	12	12	8	13	8	10
Small flat	36	18	28	31	32	34	33	28	33	22	30
Discard	12	3	7	11	12	15	15	7	13	4	10

Urbana, 1946

Grade	Iowa L304A	ILL. Hy	Ohio 07	Iowa L317	Ind. P8	Ind. 38-11	Ind. B2	Ind. WF9	Nebr. N6	Kans. K230	Mean
Round	11	14	11	10	14	10	7	11	10	8	11
Extra large flat	1	1	1	1	0	0	0	1	1	0	1
Large flat	28	21	29	24	14	18	12	20	27	9	20
Medium flat	38	39	41	39	40	41	37	41	43	33	39
Thick flat	4	6	4	5	8	6	5	5	4	7	5
Small flat	16	17	12	18	22	21	32	20	13	34	20
Discard	2	2	2	3	2	4	6	3	2	8	3

Urbana, 1946

Grade	U.S. Cl.21E	Ind. 38-11	Kans. K201C	Kans. K4	Iowa L317	U.S. Cl.7	Kans. Kys	Kans. K155	Tenn. T8	U.S. Cl.3A	Mean
Round	11	9	12	6	9	9	6	8	11	10	9
Extra large flat	5	2	17	1	4	1	2	6	4	3	4
Large flat	38	23	50	20	30	28	21	41	41	32	32
Medium flat	33	37	17	35	35	34	33	32	34	36	33
Thick flat	3	6	1	7	4	4	7	3	3	5	4
Small flat	8	18	2	24	14	19	22	8	7	12	13
Discard	2	5	1	7	3	4	8	2	1	2	4

Urbana, 1946

Grade	Ind. H21	U.S. Cl.61	Kans. K64	Ky. 27	ILL. R30	Kans. K55	Ind. 33-16	Kans. K6			Mean
Round	10	11	10	9	10	10	11	12			10
Extra large flat	14	34	16	8	13	13	7	13			15
Large flat	40	40	40	39	48	52	39	46			43
Medium flat	27	10	26	30	23	20	32	23			24
Thick flat	2	1	2	3	2	1	3	2			2
Small flat	6	2	5	9	3	2	7	3			5
Discard	2	1	1	2	1	1	2	1			1

DeKalb, 1948

Grade	ILL. M14	Iowa B8	Iowa L289	Minn. A73	Minn. A206	Minn. A334	Ohio Oh5	Ohio Oh43	Ohio Oh51A	Wisc. W22	Mean
Round	10	10	12	11	13	9	9	11	9	9	10
Extra large flat	1	5	9	4	5	1	0	8	6	1	4
Large flat	23	35	43	31	36	19	14	39	41	18	30
Medium flat	34	31	26	33	30	33	34	29	30	36	32
Thick flat	8	5	4	6	5	7	11	4	4	9	6
Small flat	19	10	5	12	8	23	24	7	7	22	14
Discard	6	3	2	3	2	9	9	2	3	6	4

TABLE 28. — MEAN PERCENTAGES OF SEED IN VARIOUS GRADES OF INBRED LINES IN ALL POSSIBLE SINGLE-CROSS COMBINATIONS, ILLINOIS (*concluded*)

Grade	DeKalb, 1948										
	ILL. R2	ILL. M14	ILL. R51	ILL R61	Ind. WF9	Iowa I.205	Ohio Oh51A	U.S. 187-2	Wisc. W22	Wisc. W24	Mean
Round	9	8	12	12	10	11	10	12	9	8	10
Extra large flat	0	1	3	2	1	1	2	3	1	1	2
Large flat	13	20	31	24	23	14	31	30	18	21	22
Medium flat	38	39	36	39	38	37	38	37	40	38	38
Thick flat	11	8	5	8	7	11	5	6	8	8	8
Small flat	22	19	11	12	16	20	10	9	20	18	16
Discard	6	5	2	4	4	6	3	3	4	5	4

Grade	Geneseo, 1948										
	ILL. Hy2	ILL. R2	ILL. R61	Ind. WF9	Ind. 38-11	Iowa B10	Iowa L317	Ohio 07	Ohio Oh41	U.S. 187-2	Mean
Round	15	14	14	12	16	16	12	12	16	14	14
Extra large flat	1	1	5	3	3	8	2	5	10	4	4
Large flat	20	23	33	30	33	40	30	39	46	35	33
Medium flat	36	42	33	34	32	25	36	32	21	33	32
Thick flat	8	8	6	6	6	3	6	4	2	5	5
Small flat	17	11	6	12	8	4	10	6	2	8	8
Discard	3	2	2	3	2	3	2	2	2	2	2

Grade	Bluffs, 1948										
	Ind. 38-11	Kans. Kys	Kans. K4	Kans. K155	Kans. K201C	Ohio 07	Okla. Ok12	Tenn. T8	U.S. Cl.7	U.S. Cl.21E	Mean
Round	11	7	6	8	14	11	9	11	8	13	10
Extra large flat	2	4	1	9	27	7	19	10	6	10	10
Large flat	34	32	30	46	46	45	57	54	35	43	42
Medium flat	33	32	37	28	11	28	12	20	31	26	26
Thick flat	5	4	4	3	1	3	1	2	3	2	3
Small flat	13	17	17	5	1	5	1	3	14	5	8
Discard	3	4	4	2	1	1	1	1	3	2	2

Grade	Bluffs, 1948										
	ILL. R30	Ind. H21	Ind. 33-16	Kans. K64	Ky. Ky27	Ky. Ky49	Ky. Ky122	Mo. Mo.RF	Mo. Mo.22	U.S. Cl.61	Mean
Round	11	9	12	11	12	12	9	13	18	15	12
Extra large flat	12	11	5	11	7	4	3	5	14	38	11
Large flat	44	47	34	48	38	28	34	35	42	39	39
Medium flat	24	24	35	24	30	35	38	31	19	5	26
Thick flat	2	2	3	2	3	4	3	5	2	1	3
Small flat	4	4	10	3	8	14	9	9	3	1	6
Discard	2	2	2	1	2	3	3	2	2	1	2

SOURCE: Jugenheimer, unpublished.

Usual certification requirements specify that "detasseling shall be so carefully done that not more than 1 percent, for any one inspection or a total of 2 percent for all inspections, of tassels of ear parent shall have shed pollen." Present strains of male sterility vary considerably, but some male-sterile single crosses shed less pollen than is tolerated by present certification and private inspection standards.

Producers may obtain slightly more and better seed from male-sterile plants than from detasseled plants. Plant food and other materials needed for normal pollen production can be translocated to the ear and used by the seed. Detasseling often decreases yields. Dungan and Woodworth (1939) reported yield reductions of 8, 15, 18 and 29 percent respectively from pulling 1, 2, 3 and 4 leaves per plant. On the other hand, detasseling without removing any leaves increased yield 1 percent over that of non-detasseled plants. Detasseling often also increases the amount of smut (*Ustilaga zeae*). By drawing on the plant for its nourishment, smut tends to lower both the quality and the quantity of the seed.

Disadvantages and problems

The present method of utilizing male sterility eliminates only part of the detasseling needed in the ordinary method of producing hybrid seed. Seed produced by the old and new techniques must be blended in order to produce sufficient pollen in the farmer's field. Great care must be taken to see that this blend is thorough. Farmers may attribute poorly filled ears to the presence of male-sterile tassels. The ultimate use of fertility-restoring genes should eliminate these objections.

The use of male sterility will not eliminate the need to inspect seed fields carefully during the pollinating season. In fact, inspection will need to be more careful and timely than ever. A few male-sterile strains shed some pollen under certain conditions. Locating the particular plants that shed pollen is difficult. Pollen shed by so-called sterile ear parent plants causes inbreeding and thus smaller yields for the farmer.

Detasseling the present hybrid seed acreage costs seed producers about 10 million dollars annually. The added expense of transferring the male sterility and pollen restorer complex to new lines and the more complicated and costly method of producing foundation seed, would off-set part of the 10 million dollars that could be saved by eliminating all detasseling. The acreage of hybrid seed produced each year should plant 100 million acres of corn. Consequently, the 10-million-dollar cost of detasseling would amount to only about 10 cents per acre.

Transferring male sterility and pollen restorers from one line to another is a complicated, highly technical, time-consuming operation (Bauman, 1952). A number of years are required to develop and test thoroughly new inbred lines. Adding sterility to new lines after they have survived necessary development and testing procedures might seriously delay a breeding program.

Male sterility and pollen restorers can be transferred from one line to another by proper breeding procedures. Such transfer, however, may be accompanied by the transfer of other genes that affect desired agronomic

characters. Thus the performance of a line may be improved or it may be impaired. Thorough testing is required to make sure that the breeding behavior of other characters was not changed by adding the sterility complex.

Present cytoplasmic male-sterile inbreds must be maintained by sibbing with fertile strains of the same line. Thus the foundation seed program may be made even more complex (Ingersoll, 1952).

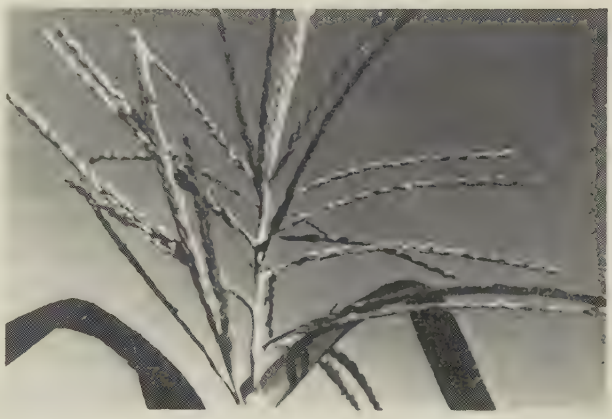


FIGURE 83. - *Cytoplasmic male sterility prevents the tassels from producing functional pollen.*

FIGURE 84. - *Use of cytoplasmic male sterility reduces the amount of detasseling needed to produce hybrid seed.*

Fields of hybrid seed will continue to need careful and timely inspections. Seed producers, experiment stations, and certification agencies must check the performance of hybrids produced by male-sterile stocks. Changes in performance of inbreds, and single crosses and double crosses, will reopen the difficult but familiar problem of proper labeling. Certification requirements for male-sterile hybrids were discussed by Scott (1953).

Breeding for cytoplasmic male sterility

Cytoplasmic male sterility in maize was described by Rhoades (1931, 1933, 1952a). This type of sterility prevents the tassels from producing functional pollen (Figure 83). It is transmitted only through the cytoplasm of the germ cells instead of through the chromosomes, as are most other characters. Various phases of cytoplasmic male sterility have been studied by Josephson and Jenkins (1948), Gabelman (1949), Schwartz (1951), Rogers and Edwardson (1952), Rogers (1953), Jones (1954), Beckett (1954), and Leng and Bauman (1955).

Male sterility does not normally occur in standard inbreds, such as WF9. Consequently, sterile cytoplasm must be introduced by crossing WF9 with the sterile strain and backcrossing the progeny to WF9 from three to five times. Only sterile plants with the characteristics of WF9 are selected in each generation. Sublines must be tested in single crosses for their freedom from pollen-restoring genes. The selected male-sterile WF9 is maintained or increased for use in seed production by crossing it with the normal WF9, using the male sterile strain as the seed parent. Fertile plants may result from contamination or reversion from sterile to fertile types. Therefore inbred and single-cross production fields of male-sterile material must be carefully rogued during pollination to eliminate any plants shedding pollen.

Genetic Pollen Restorers

Many seed organizations utilize cytoplasmic male sterility to produce hybrid seed (Figure 84). This type of sterility reduces the amount of detasseling needed to produce seed of the cross. However, the double-cross grown by farmers is also sterile. To insure pollination of the farmer's crop, ample pollen may be provided by blending seed produced through use of male sterility with seed produced in the ordinary way by detasseling the ear parent. The two lots of seed should be grown under similar conditions so that they will grade the same. The procedure involved in producing seed of Ill. 1570 without detasseling is shown in Table 29.

TABLE 29. — UTILIZING MALE STERILITY TO ELIMINATE PART OR ALL OF THE DETASSELING NEEDED FOR THE PRODUCTION OF HYBRID SEED OF ILL. 1570

Year	Seed parent		Pollen parent	Seed parent		Pollen parent
First	Inbred WF9 (Male sterile)	×	Inbred 38-11 (Normal)	Inbred Oh41 (Normal)	×	Inbred Hy2 (Normal)
	Requires no detasseling		Provides pollen	Must be detasseled		Provides pollen
Second	WF9 x 38-11 (Male sterile)					Oh41 x Hy2 (Normal)
	Requires no detasseling					Provides pollen
Third	ILL. 1570 grown by farmer. Provision may be made for adequate pollen production in the field in the second year by (1) producing two thirds of the required hybrid seed on the male-sterile seed parent and one third of the seed on the normal seed parent and thoroughly mixing the seed, or (2) using a single-cross male parent carrying genes that counteract the sterile cytoplasm and restore pollen production in the resulting crop.					

Breeding for restorer genes

Fertility may be restored in the double-cross hybrid if one or both inbreds in the male parent single cross contains effective male fertility restorer genes. Breeding for pollen restorers has been discussed by Jones and Mangelsdorf (1951), Rogers (1955), and by Edwardson (1955). Eckhardt (1953, 1954) showed that fertility-restoring genes may be added to non-restoring inbred lines by backcrossing if the process is carried out on a background of male-sterile cytoplasm.

TABLE 30. — PROCEDURE FOR DEVELOPING BOTH MALE-STERILE AND FERTILITY-RESTORING STRAINS OF ILL. HY2

Generation	Seed parent		Pollen parent
(1)	Inbred with Texas source of cytoplasmic male sterility.	×	Inbred with dominant fertility-restorer gene.
	cms rf rf		Rf Rf
(2)	F_1 with male-sterile cytoplasm and fertile tassels.	×	III. Hy2 with normal cytoplasm and needing fertility-restorer gene.
	cms Rf rf		rf rf
(3)	Segregate with male-sterile cytoplasm and fertile tassels.	×	III. Hy2 used as recurrent parent.
	cms Rf rf		rf rf
	Segregate with male-sterile cytoplasm and sterile tassels.		
	cms rf rf (Discarded)		
(4)+	Back-cross plants with male-sterile cytoplasm and fertile tassels as seed parent with ILL. Hy2 as pollen parent. After several back crosses, self pollinate fertile segregates and select homozygous fertility-restoring strain (cms Rf Rf) of ILL. Hy2. Sterile segregates (cms rf rf) can be crossed with the original ILL. Hy2. This is the male sterile strain of ILL. Hy2.		

SOURCE: Modified from Eckhardt, 1953

Procedure for developing both male-sterile and fertility-restoring strains of inbred lines is shown in Table 30. This procedure eliminates test crosses that are required if normal cytoplasm is used in the transfer of the fertility-restoring gene. Eckhardt (1953) pointed out that:

"The basic starting material is the F_1 cross between the cytoplasmic male-sterile source and the fertility restorer source. This fertile F_1 carrying male-sterile cytoplasm is used as female parent in the cross with an inbred that is to have the fertility restorer factors added. Backcrossing is now carried out using the fertile male-sterile cytoplasm segregates as female and the inbred as recurrent parent. After adequate backcrossing:

1. Fertile segregates can be selfed and the homozygous fertile line selected — this is the inbred line with restorer factors added.
2. Sterile segregates can again be crossed with the inbred — this is the male sterile inbred line."

PART IV

Development and Testing of Hybrids

16. UTILIZATION OF INBRED LINES IN HYBRIDS

Reasons for Crossing

All inbred lines of maize so far developed are inferior to open-pollinated varieties in vigor and yield. Until such time as decidedly more productive lines are developed, the ultimate use of inbred lines of commercial maize growing is in the production of hybrids. The better hybrid combinations of selected lines give substantial increases in yield over the better open-pollinated varieties. Other desirable characteristics, such as strength of stalks and of roots, and resistance to specific diseases and insects are advantages which *some* hybrids possess. Not all hybrids are worthwhile; some are much less desirable than average open-pollinated varieties. In order to develop a satisfactory hybrid, the maize breeder must make and test a large number of crosses among his outstanding inbred lines. When a desirable combination is found, however, it can be expected to perform in the same way each time it is grown under the same environmental conditions.

Methods of Crossing

Hybrids may be made by hand-pollination or by growing two strains in alternate blocks in an isolated plot and detasseling, before they have shed any pollen, all of the plants of the strain on which seed is to be produced.

Experimental hybrids requiring only small quantities of seed may be made by hand-pollination. The technique of making hand-pollinations was described in Chapter 7. Paired rows are useful aids in the making of crosses. Pollen is taken from plants in one row and used on the silks of plants in the other row. Obviously the length of the rows will depend upon the amount of seed required.

Types of Hybrids

Several kinds of hybrids are possible, depending upon the number and arrangement of the parental inbred lines. These include single, three-way, double, multiple, top, and back crosses (Table 31).

TABLE 31. — KINDS OF HYBRIDS DEPEND UPON THE NUMBER AND ARRANGEMENT OF THE PARENTAL INBRED LINES

Type of hybrids	Pedigree
Single cross	A × B
Three-way cross	(A × B) × (C)
Double cross	(A × B) × (C × D)
Multiple cross	[(A × B) × (C × D)] [(E × F) × (G × H)]
Top cross	A × Open-pollinated variety, or (A × B) × Open-pollinated variety
Back cross	[(A × B) × A] × [(C × D) × C]
Single-back cross	[A × B] × [(C × D) × C]
Synthetic	Composite of many lines

The simplest hybrid, known as a single cross, is made by combining two inbred lines. Single crosses tend to be slightly higher yielding and more uniform in plant and ear characteristics than other types of hybrids, as shown in Table 32, page 239. The single cross is used extensively for commercial sweet corn production where uniformity is of extreme importance. High cost of seed is the principal objection to single crosses for field production. Single-crossed seed, of necessity, is produced on inbred plants, which are relatively poor producers of seed and pollen. This makes the cost of producing single-crossed seed relatively great because the yield is small. When the single-crossed seed is used only as parent stock for making double-crossed seed, however, the quantity needed is small, and its high cost is relatively unimportant. Single-cross data are valuable in predicting the performance of desirable double-cross hybrids.

Seed of three-way crosses is less expensive to produce than that of single crosses but more expensive than that of double crosses. Three-way crosses tend to be more uniform and slightly higher yielding than double crosses (Table 32). In most cases they are produced where three lines are available which combine well, but where a suitable fourth inbred is lacking, or where extreme uniformity is desired. Three-way crosses also are useful in predicting desirable double cross hybrids (see Chapter 17). Three-way crosses are used quite widely in the United States for the production of popcorn.

Double crosses are the most widely used type of hybrid. Double-crossed seed is produced on single-crossed plants, which are highly productive of quality seed. Single-crossed plants, likewise, produce pollen abundantly. This makes possible a greater proportion of seed-producing rows to pollen rows in the crossing fields. Furthermore, single-crossed plants

withstand adverse conditions much better than inbred plants, reducing the risk in seed production. All of these factors have an important bearing on the cost of producing seed. Double crosses are slightly more variable in plant characters than single crosses or three-way crosses, which may be an advantage when the crop is grown under adverse conditions (Table 32).

Multiple crosses, involving six, eight or more inbred lines, have been used very little commercially. They may be useful under adverse conditions where lower seed costs or greater variability in the crop are important factors. However, they are more complicated to produce than hybrids involving fewer lines, and usually are not the highest yielding type of hybrid when used under desirable growing conditions.

The most desirable hybrids for use under hot, dry weather conditions might be those with considerable variation in the date of pollination. This may be accomplished by the use of:

1. top crosses of desirable inbred lines with adapted varieties;
2. double crosses or multiple hybrids involving early and late maturing lines;
3. a mechanical mixture of two or more adapted hybrids differing in maturity;
4. planting one maturity hybrid in one planter box and another maturity in the other planter box.

Advanced generations of multiple hybrids also serve as valuable germplasm sources of new inbred lines.

Top crosses are simple to produce and often are useful hybrids for use in early stages of a breeding program. For example, a single cross from the Corn Belt of the United States may contribute genes for high yield and standability. An open-pollinated variety in some sections of Europe might contribute adaptation to local European conditions. Thus, such top crosses may combine the desirable traits of the American single cross and the European open-pollinated variety. Most top crosses, however, are temporary expedients which usually are eventually replaced by double crosses. Top crosses are useful for evaluating the performance of inbred lines. They also provide a means of selecting promising open-pollinated varieties for use as source material for the development of inbred lines.

Backcross hybrids are not being used extensively at the present time. They are complicated and expensive to produce. However, as shown in Table 32, backcross hybrids may give excellent performance and reasonable uniformity of plant and ear.

Single-backcross hybrids may perform extremely well, contribute uniformity of plant and ear, and be very practical to produce, inasmuch as the seed is grown on a vigorous single-cross parent (Table 32).

TABLE 32. — PERFORMANCE AND UNIFORMITY OF VARIOUS TYPES OF HYBRIDS INVOLVING INBRED LINES HY, L317, WF9 AND 38-11, URBANA, ILLINOIS, 1948

Type of material	Acre yield, bu.	Ear weight, gm.	Ear length, in.	Ear circum-ference, in.	Kernel rows, no.	Ear height, in.
	Performance					
4 inbred lines	40.9	127.12	6.53	4.96	16.02	35.48
6 single crosses	104.6	282.83	8.70	5.70	18.03	49.18
12 three-way crosses	99.7	276.61	8.56	5.69	17.69	49.83
12 single-back crosses	101.9	274.63	8.43	5.73	17.59	49.75
12 back crosses	104.6	279.15	8.59	5.72	17.49	50.34
3 double crosses	98.1	272.92	8.55	5.66	17.53	50.63
6 top crosses	96.8	267.07	8.59	5.56	17.16	48.15
1 open-pollinated variety	91.3	256.34	8.11	5.63	16.88	45.92
Mean	92.2	254.58	8.26	5.58	17.30	47.41
	Coefficients of variability					
4 inbred lines	..	33.45	15.46	6.51	9.39	12.23
6 single crosses	..	22.18	9.89	5.33	9.12	7.62
12 three-way crosses	..	23.69	10.76	6.02	9.83	9.61
12 single-back crosses	..	22.94	10.75	6.17	11.10	10.15
12 back crosses	..	23.38	11.24	6.11	11.78	10.33
3 double crosses	..	24.33	11.84	6.97	12.62	10.63
6 top crosses	..	24.39	11.94	6.86	12.02	14.19
1 open-pollinated variety	..	26.02	12.82	6.73	13.60	13.60
Mean	..	25.05	11.84	6.34	11.18	11.04

SOURCE: Jugenheimer, unpublished data.

Synthetics are produced by compositing selected inbred lines. Advanced generation seed of multiple crosses are termed "synthetic varieties." Brieger (1950) proposed a balanced population technique for developing synthetic varieties. Their performance may not be greatly superior to that of open-pollinated varieties. Synthetics are proving to be very useful reservoirs of desirable gene combinations for the development of superior inbred lines.

TABLE 33. — THE RELATIVE VARIABILITY OF OPEN-POLLINATED VARIETIES AND HYBRIDS OF MAIZE

Characters	12 open-pollinated varieties	22 top crosses	49 double crosses	53 single crosses
	Standard deviations			
Plant height, inches	7.24	6.57	6.26	5.43
Ear height, inches	5.65	4.68	4.69	3.67
Nodes per plant	1.36	1.05	1.05	0.82
Nodes below ear	1.14	0.85	0.90	0.70
Kernel rows	2.16	1.60	1.62	1.46
	Coefficients of variability			
Plant height, inches	11.1	10.7	9.7	8.5
Ear height, inches	17.4	15.2	14.3	11.5
Nodes per plant	9.5	7.7	7.6	6.1
Nodes below ear	15.9	12.2	12.6	10.0
Kernel rows	12.9	10.7	11.6	10.0
Mean (C.V.)	13.4	11.3	11.2	9.2

SOURCE: Arnold and Jenkins, 1932.

Performance, Uniformity and Practicability

Arnold and Jenkins (1932) reported on the relative variability of open-pollinated varieties and hybrids. As shown in Table 33, the open-pollinated varieties were more variable than the hybrids. The single crosses were most uniform, and the double crosses and top crosses were approximately midway in variability.

Jugenheimer (1936) compared inbred lines in top crosses, three-way crosses, and double crosses. In percent of the open-pollinated varieties, the yields of the hybrids averaged: top crosses, 114.6; double crosses, 125.9; and three-way crosses, 128.1 (Table 34).

TABLE 34. — COMPARISON OF OPEN-POLLINATED VARIETIES AND INBRED LINES IN TOP CROSSES, DOUBLE CROSSES AND THREE-WAY CROSSES

Set	Open-pollinated varieties	Top crosses	Double crosses	3-way crosses
	..... *Yields in percent of open-pollinated varieties*			
1	100.0	136.5	150.0	153.8
2	100.0	106.4	118.9	119.6
3	100.0	100.9	108.9	111.0
Mean	100.0	114.6	125.9	128.1
	..... *Ear size (ears per cwt., no.)*			
1	450	378	371	349
2	425	436	409	402
3	352	346	332	324
Mean	409	387	371	358

NOTE: Nine inbred lines were included in each set, means of 1934 and 1935.
SOURCE: Jugenheimer, 1936.

The relative performance and uniformity of plant and ear characteristics of various types of hybrids were studied by Jugenheimer (1948b). Four inbred possible combinations to produce six single crosses, 12 three-way crosses, 12 single back crosses, 12 back crosses, three double crosses and six top crosses. Results are shown in Table 32.

The theoretically homozygous inbred lines were more variable than the hybrids in ear weight, ear length, and ear height, which are traits greatly influenced by the environment. The inbred lines were uniform in the number of kernel rows, which trait is determined primarily by genetic factors and affected very little by the environment.

Highest yields and greatest uniformity were obtained from the single cross, three-way cross, single-back cross and backcross hybrids (Table 35).

TABLE 35. — DIFFERENCES IN ACRE YIELD OF INBRED LINES, VARIOUS TYPES OF HYBRIDS, AND AN OPEN-POLLINATED VARIETY

Type of material	Inbreds	SC	3-W	S-BC	BC	DC	TC	OP
	Bushels							
Inbred lines	—	+ 63.7	+ 58.8	+ 61.0	+ 63.7	+ 57.2	+ 55.9	+ 50.
Single crosses	− 63.7	—	− 4.9	− 2.7	+ 0.0	− 6.5	− 7.8	− 13.3
Three-way crosses	− 58.8	+ 4.9	—	+ 2.2	+ 4.9	− 1.6	− 2.9	− 8.4
Single-back crosses	− 61.0	+ 2.7	− 2.2	—	+ 2.7	− 3.8	− 5.1	− 10.6
Back crosses	− 63.7	0.0	− 4.9	− 2.7	—	− 6.5	− 7.8	− 13.3
Double crosses	− 57.2	+ 6.5	+ 1.6	+ 3.8	+ 6.5	—	− 1.3	− 6.8
Top crosses	− 55.9	+ 7.8	+ 2.9	+ 5.1	+ 7.8	+ 1.3	—	− 5.5
Open-pollinated variety	− 50.4	+ 13.3	+ 8.4	+ 10.6	+ 13.3	+ 6.8	+ 5.5	—

NOTE: Underlined differences exceed 5 percent level of significance.
SOURCE: Jugenheimer, unpublished.

Single-cross hybrids were slightly higher yielding and more uniform than other types of hybrids. The relatively high cost of producing seed of single crosses limits their use to situations where extreme uniformity is important.

Double crosses (the most widely-grown type of hybrid) and top crosses were considerably lower yielding and more variable in plant and ear traits than the other types of hybrids. Eight of the 12 single-backcross hybrids yielded more grain than the best double cross. The best single-backcross hybrid yielded nine bushels (nearly 10 percent) more than the best double cross hybrid.

Seedsmen are interested in hybrids with greater uniformity and performance than double cross hybrids used at present. Single backcross hybrids appear to offer commercial utilization. They produce higher grain yields, contribute greater uniformity of plant and ear, and are practical to produce, inasmuch as the seed is grown on a vigorous single-cross parent.

17. PREDICTING THE PERFORMANCE OF HYBRIDS

Prediction studies are an extremely valuable part of a research program. Methods are available which enable maize breeders to predict the performance of the better hybrid combinations without making and testing literally thousands of undesirable crosses. Predicted hybrid combinations, however, should always be thoroughly tested under field conditions before being put into commercial production.

Prediction Methods

Jenkins (1934) reported on the relative efficiency of four methods of predicting the performance of double-cross hybrids. Characters studied were burned leaves, ear height, erect plants at harvest, moisture content of the grain, shelling percentage, and acre yield of grain.

The four prediction methods used by Jenkins were:

A. The mean value for any character of the six all-possible single cross combinations among four inbred lines.

B. The mean value of the four nonparental single crosses among four inbred lines.

This method has the soundest genetic basis and provides information on the performance of the three all-possible double-cross combinations involving four inbred lines. Jenkins pointed out that:

> "In any double cross, the genes of each of the four inbreds are united with the allelomorphs of the two lines which entered the double cross from the opposite parent."

C. The mean value of all single crosses in which an inbred line was one parent.

D. The mean value of top crosses for any given four inbred lines.

The positive correlations for grain yield of methods A, B, C, and D were 0.75, 0.76, 0.73, and 0.61 respectively. A correlation of 0.39 was statistically significant.

Sprague (1955) points out that:

"Methods A, C, and D assume additive gene action, i. e., a gene contributed by any line will produce its characteristic effect regardless of the order of pairing..... Method B permits the recognition of non-additive effects arising from dominance, epistasis, etc."

Correlations Between Predictions and Actual Results

The effectiveness of predicting the performance of double crosses from the mean yields of the four nonparental single crosses has been tested by many workers. Anderson (1938) obtained a correlation of 0.90 between the predicted and observed yields of 15 double crosses. Hayes, Murphy and Rinke (1943) compared 114 double crosses under conditions that were different from those under which the single crosses were tested. Correlations, however, between predictions and actual results were 0.48 for yield and 0.21 for moisture content. The method has been used by many workers.

Importance of Permutations

Doxtator and Johnson (1936) reported that the order of pairing inbred lines affected the predicted and actual yields of hybrids.

Eckhardt and Bryan (1940a) found that the highest yielding double crosses were those that had the inbred lines from the same open-pollinated variety on the same sides. For example, inbred lines A and B were developed from one open-pollinated variety, and Y and Z were developed from another variety. Double cross (A x B) (Y x Z) was higher yielding than (A x Y) (B x Z) or (A x Z) (B x Y). Lower variances were obtained from ear height, ear length, plant height, and ear weight for A x B or Y x Z crosses than for A x Y, A x Z, B x Y, or B x Z crosses.

Interesting results were obtained by Eckhardt and Bryan (1940b) by crossing early (E) and late (L) inbred lines. Variances for silking date, ear height, ear weight, ear length, and ear diameter were significantly less for (E x E) (L x L) hybrids than for (E x L) (E x L) combinations.

Procedures for Making Predictions

The making and testing of all-possible hybrid combinations among available inbred lines is a tremendous task. For example, it is possible to produce 100 top crosses, 4,950 single crosses, and 11,763,625 double crosses with only 100 inbred lines.

Top crosses may be used for the rapid, preliminary evaluation of inbred lines. A group of 100 inbred lines may be crossed with an open-pollinated variety or synthetic tester in a detasseled crossing plot in which the tester is used as the pollinating parent. The 100 top crosses are compared the next season in field tests to evaluate the inbred lines for general combining ability.

TABLE 36. — ACRE YIELD AND STANDABILITY OF 10 INBRED LINES AND 45 SINGLE CROSSES

Parent lines	(0) U.S. C.I.21E	(1) Ind. 38-11	(2) Kans. K201C	(3) Kans. K4	(4) Iowa L317	(5) U.S. C.I.7	(6) Kans. Kys	(7) Kans. K155	(8) Tenn. T8	(9) U.S. C.I.3A
	Yield per acre, bushels									
(0) C.I.21E	63.2/	131.6	133.0	125.6	137.7	118.4	120.8	132.6	129.2	123.2
(1) 38-11	131.6	56.8/	117.4	128.3	119.0	129.0	120.4	118.6	117.6	121.0
(2) K201C	133.0	117.4	41.7/	118.6	127.2	110.2	111.6	107.8	104.0	112.4
(3) K4	125.6	128.3	118.6	33.3/	109.3	118.0	117.9	113.5	108.8	99.1
(4) L317	137.7	119.0	127.2	109.3	44.8/	109.6	110.8	108.1	110.2	106.5
(5) C.I.7	118.4	129.0	110.2	118.0	109.6	62.7/	120.5	114.4	109.4	108.1
(6) Kys	120.8	120.4	111.6	117.9	110.8	120.5	42.4/	111.2	125.4	98.6
(7) K155	132.6	118.6	107.8	113.5	108.1	114.4	111.2	21.8/	118.3	93.3
(8) T8	129.2	117.6	104.0	108.8	110.2	109.4	125.4	118.3	45.1/	77.6
(9) C.I.3A	123.2	121.0	112.4	99.1	106.5	108.1	98.6	93.3	77.6	31.7/
Mean	128.0	122.5	115.8	115.5	115.4	115.3	115.2	113.1	111.2	104.4
	Percent of erect plants at harvest									
(0) C.I.21E	95/	89	92	58	68	90	86	97	94	66
(1) 38-11	89	88/	94	84	80	96	48	86	96	74
(2) K201C	92	94	90/	92	82	94	85	92	96	72
(3) K4	58	84	92	25/	52	76	62	63	70	50
(4) L317	68	80	82	52	38/	76	9	44	58	30
(5) C.I.7	90	96	94	76	76	81/	80	79	76	68
(6) Kys	86	48	85	62	9	80	50/	70	86	40
(7) K155	97	86	92	68	44	79	70	97/	83	55
(8) T8	94	96	96	70	58	76	86	88	95/	40
(9) C.I.3A	66	74	72	50	30	68	40	55	40	46/
Mean	82	83	89	68	55	82	63	75	78	55

NOTE: A difference of less than 14.4 bushels between any two single-cross yields is not significant.
Numbers in ( ) are inbred line codes used in Table VI in the Appendix.
Data in __/ are on the inbred lines.

SOURCE: Jugenheimer, Leng and Woodworth, 1947c.

Often the 10 inbred lines which performed best in top crosses are combined in 45 all-possible single crosses. These single crosses are compared in performance tests, and the data permit predicting the performance of 630 double-cross combinations (Table 36).

Use of forms for individual double crosses provide an easy method of making predictions where punched card equipment is not available. Samples of such forms are shown in Tables 37 and 38. Since the performance of 630 double crosses can be predicted from 45 single crosses involving 10 selected inbred lines, the appropriate hybrid numbers, pedigrees, and code numbers from Table VI in the Appendix should be copied onto 630 forms similar to Table 37.

TABLE 37. — THE PERFORMANCE OF THIS DESIRABLE DOUBLE-CROSS HYBRID WAS PREDICTED FROM SINGLE-CROSS DATA IN TABLE 36 BY USING THE CODE NUMBERS FROM TABLE VI IN THE APPENDIX

57	$\frac{(0 \times 3) \times (1 \times 2)}{(\text{C.I. 21E} \times \text{K4}) \times (38\text{-}11 \times \text{K201C})}$													
Hybrid no.	Pedigree													
Non-parental singles	Acre yield	Days to half-silk	Moisture	Shelling	Erect plants	Stand	Height		Ears per cwt.	Ears per plant	Damaged kernels	Smutted plants	Suckers	Dropped ears
							Plant	Ear						
Code	Bu.	No.	..... Percent				Ft.	In.	.. Number ..		..... Percent			
0 X 1	131.6				89									
0 X 2	133.0				92									
3 X 1	128.3				84									
3 X 2	118.6				92									
Sum	511.5				357									
Mean	127.9				89									

The use of forms for predicting the performance of double crosses is shown in Tables 37 and 38. Data for predicting the performance of hybrid numbers 57 and 614 were obtained from Table 36. The actual inbred lines are coded from 0 to 9 for convenience. Predicting the standability of hybrid number 57 requires using data from non parental single crosses 0×1, 0×2, 3×1, and 3×2, which had the respective percentages of erect plants 89, 92, 84, and 92, or a mean prediction of 89 percent (Tables 36 and 37). Hybrid number 614 requires erect plant data on non-parental singles 4×6, 4×8, 9×6, 9×8, which had 9, 58, 40, and 40 percent erect plants respectively, or a prediction of 37 percent (Tables 36 and 38). Predicted performance of other agronomic characters may be made in a similar manner.

TABLE 38. — THE PERFORMANCE OF THIS UNDESIRABLE DOUBLE-CROSS HYBRID WAS PREDICTED FROM SINGLE-CROSS DATA IN TABLE 36 BY USING THE CODE NUMBERS FROM TABLE VI IN THE APPENDIX

614	$\frac{(4 \times 9) \times (6 \times 8)}{(L317 \times C.I.\ 3A) \times (Kys \times T8)}$														
Hybrid no.	Pedigree														
Non-parental sirgles	Acre yield	Days to half-silk	Moisture	Shelling	Erect plants	Stand	Height		Ears per cwt.	Ears per plant	Damaged kernels	Smutted plants	Suckers	Dropped ears
							Plant	Ear						
Code	Bu.	No.	..... Percent				Ft.	In.	.. Number ..		..... Percent			
4 X 6	110.8				9									
4 X 8	110.2				58									
9 X 6	98.6				40									
9 X 8	77.6				40									
Sum	397.2				147									
Mean	99.3				37									

Three-way crosses also provide useful predictions of the performance of double-cross hybrids. A large number of inbred lines can be compared, and the method is especially valuable where a desirable seed parent single cross is available for use as a tester. Use of three-way cross data provides information on specific hybrids and often may eliminate the time and expense required for testing inbred lines in top crosses and single crosses.

The procedure in predicting " acre yields " and " percentage of erect plants " from three-way cross data is shown in Table 39. Three-way cross data are from Table 40.

TABLE 39. — PROCEDURE IN PREDICTING THE PERFORMANCE OF DOUBLE CROSS HYBRIDS FROM THREE-WAY CROSS DATA IN TABLE 40

(WF9 × I.205) (B33 × Oh43)			(WF9 × I.205) (187-2 × W86)		
	Acre yields	Erect plants		Acre yields	Erect plants
	Bu.	%		Bu.	%
(WF9 × I.205) × B33	109	90	(WF9 × I.205) × 187-2	93	81
(WF9 × I.205) × Oh43	113	96	(WF9 × I.205) × W86	97	67
	2 | 222	2 | 186		2 | 190	2 | 148
Prediction	111	93	Prediction	95	74

TABLE 40. — PERFORMANCE OF THREE-WAY CROSSES

Inbred line	Acre yield, bu.	Moisture in grain, %	Shelling, %	Erect plants, %	Stand, %	Height		Smutted plants, %	Dropped ears per acre, no.	Corn borer damage score
						Plant, ft.	Ear, in.			
	M14 × 187-2 (common parent)									
WF9	102	18	78	82	98	8.4	34	0	300	2.0
1.205	89	19	82	82	99	8.0	38	1	300	3.1
B32	91	18	82	51	99	8.5	36	1	600	4.0
B33	100	19	77	66	98	8.9	38	3	600	2.8
B34	103	17	81	93	100	8.6	37	1	100	2.8
N1	113	18	80	51	99	9.0	40	4	300	3.6
N2	87	18	79	47	98	9.1	43	4	100	4.5
N6	109	20	81	77	100	8.2	38	3	200	3.4
Oh7B	90	19	80	85	82	8.8	38	2	0	2.3
Oh43	100	17	83	87	96	8.0	30	0	500	2.8
W22	90	17	82	78	99	8.2	34	4	300	3.0
W64	86	18	81	61	98	8.1	34	1	0	2.8
W72	86	23	81	67	100	8.4	34	2	300	3.1
W86	100	17	78	78	99	8.2	38	1	600	1.6
W112	100	19	81	81	96	8.6	39	1	400	1.8
W144	94	20	80	82	98	8.5	36	4	1 000	2.3
	WF9 × 1.205 (common parent)									
B32	92	19	81	81	95	8.9	39	1	2 000	2.3
B33	109	19	77	90	89	9.0	40	0	1 900	1.8
B34	82	17	79	93	99	8.1	35	4	200	2.8
N1	110	18	81	79	98	9.2	40	0	400	2.5
N2	71	22	77	84	89	8.9	39	6	1 000	2.1
N6	109	19	80	88	100	8.5	36	1	1 000	2.8
Oh7B	107	18	81	92	87	8.9	37	2	600	1.8
Oh43	113	18	80	96	99	8.5	33	1	600	2.1
W22	89	18	79	93	97	8.5	35	4	800	1.6
W64	92	19	82	90	96	8.6	38	2	600	1.8
W72	80	17	78	92	93	8.2	36	2	1 400	2.0
W86	97	19	81	67	99	8.8	37	2	600	3.3
W112	104	20	80	86	93	8.6	37	1	200	2.0
W144	90	19	80	96	99	8.6	35	6	1 100	1.3
187-2	93	18	82	81	94	9.1	42	4	400	2.1
M14	94	19	80	88	96	8.4	33	5	900	2.5

SOURCE: Jugenheimer, Bauman, Alexander, and Woodworth, 1950.

The Illiac electronic digital computer is used at the University of Illinois for predicting the performance of hybrids from single cross or three-way cross data. This is a very efficient procedure. In general, each hour on the Illiac is equivalent to over 300 hours of desk calculator time. The computed predictions are printed on sheets by the tele-typewriter. Details of the development and operation of this program have been given by Jacob (1956) of the University of Illinois Agronomy Department.

18. FIELD PLOT TECHNIQUE

Newly developed hybrids must be compared carefully under local conditions before any can be recommended for general growing. Application of modern field plot technique is required for the efficient management of performance trials, obtaining of reliable information, and intelligent interpretation of the results. Hayes, Immer and Smith (1955) presented a discussion of this subject.

Choice of Location

The soil and climatic conditions of the test field should be similar to those under which the crop will be grown by farmers. Another requirement of satisfactory performance tests is a uniform field. The soil in many fields is heterogeneous because of differences in topography, variations in fertility, differences in soil moisture, and previous cropping systems. The nature and extent of soil heterogeneity may be determined through the use of uniformity trials or blank tests.

Controlling Competition

Often the plants growing on the sides and ends of plots are more vigorous and higher yielding than those in the center of the plot because of greater available fertility, light, and water supply. Intervarietal competition between strains differing in maturity or size can be controlled by planting multiple row plots and discarding the border rows before harvesting. Obviously, such procedure requires more land and labor than smaller plots.

Size and Shape of Plot

The size and shape of a plot affects the accuracy of a test. Increasing the plot size within certain limits usually results in decreasing the error of a single-plot yield. Increasing the plot size, however, also increases the

land area in the blocks, which usually results in greater heterogeneity within the blocks. Optimum plot size is usually a compromise between these two opposing tendencies. Experience has shown that long, narrow plots usually have a lower error than square ones. Long, narrow plots should be planted at right angles to the direction of the fertility contours.

Bryan (1933) concluded that one half as many plants of maize were required to obtain the same level of precision in testing the yielding ability of hybrids as compared with open-pollinated varieties. Most maize breeders use either 2×5-hill (30-40 plants) or 2×10-hill (60-80 plants) plots. In general, smaller plots may be used for comparing the more uniform single crosses than for double crosses or open-pollinated varieties.

Jugenheimer (1948a, 1949a, 1954b and unpublished) used replicated single-hill plots for the preliminary screening of large numbers of test crosses. Efficient use of single-hill plots for testing requires uniform soil and practically perfect stands. A four-replication test of 2,000 hybrids compared in "microtests" requires about 2 acres of land compared to 40 acres for standard 2×10-hill plots. Obviously, it is easier and less expensive to obtain two acres of uniform soil than 40 acres for the preliminary evaluation of large numbers of hybrids. Savings of land, labor and time are other advantages of the use of microtests. They appear to be efficient for evaluating yield, maturity, plant and ear height, and resistance to diseases and insects. Some workers, however, prefer larger plots for testing hybrids in order to observe more plants.

Need for Replication

Increasing the number of replications usually reduces experimental error much more rapidly than does increasing the size of plots. The mean of several replications provides a more accurate measure of the performance of an entry than does one plot. In general, accuracy is increased in proportion to the square root of the number of replications.

Replication may increase the scope of an experiment. Replications differing in fertility, rate of planting, etc., may add to the information obtained from the test. Obviously, conditions within the individual replications should be as uniform as possible.

Replication provides information which permits an estimate of uncontrolled variation known as experimental error. Replication also permits the use of experimental designs that aid in the control of error.

The number of replications required in a performance test depends upon the variability of the soil, the variability of the material to be tested,

the degree of accuracy desired, and the amount of available seed, land, and labor. "The standard error of the mean will be $s/\sqrt{N}$, where s is the standard error of a single determination and N is the number of plots of each variety or treatment" (Hayes, Immer and Smith, 1955). The number of replications required to reduce the standard error to the degree of precision desired may be determined by the formula:

$$\left(\frac{\text{Standard error of a single determination}}{\text{Standard error desired}}\right)^2$$

From three to six replications are used in most performance tests.

Maize breeders sometimes find that the differences necessary for statistical significance are greater than hereditary differences between the hybrids to be tested. Tests by Jugenheimer (1954b) indicate that replicated, single-hill plots are useful for accurate evaluation of hybrids of similar performance. These micro-tests require less seed, permit testing more replications, more material, under more varying conditions, and at lower cost than larger plots.

Desirability of Randomization

Randomization requires that each entry be distributed at random within a replication. R. A. Fisher pointed out that randomizing the order of entries in a block permitted an unbiased estimate of error. It insures that an entry will not be consistently favored or handicapped in each replication by known or unknown sources of variation. Published tables of random numbers, numbered beans or cards may be used to obtain the randomization of entries in each replication.

Statistics

Interpreting the results of modern performance trials involves the use of statistics. Therefore, the terminology and symbols in common use will be briefly reviewed.

Three measures of type are:

1. *Mean*, or arithmetic average, is the sum of the observations or measures divided by their number.
2. *Mode* is the class of greatest frequency in a series.
3. *Median* is the middle individual in a series.

Several measures of variability include:

1. *Standard deviation* is a measure of variability in terms of the units of measurement.
2. *Standard deviation of a sample mean* measures the degree of variation among the means of a series of samples.
3. *Variance* is the square of the standard deviation.
4. *Coefficient of variability* is a measure of variability expressed in percentage of the mean, making it possible to compare the relative variability of two populations with widely different means.

Some measures of association are:

1. *Coefficient of correlation* is used as a measure of the degree of association between two characters worked with at the same time. A perfect positive correlation is + 1, and a perfect negative correlation is — 1. No correlation is given by r = 0. Intermediate values denote association of an intermediate degree. Types of correlation are simple, partial, and multiple.
2. *Regression coefficient* gives the rate of change in one variable (dependent variable) per unit rate of change in another (independent variable).

Analysis of variance is used to determine the significance of results by separating the total variation into a number of components attributable to known or controlled sources of variation and leaving a residual portion due to uncontrolled causes, which is called the error. The "t" test evaluates the difference between two means, while analysis of variance permits evaluation of differences among many means.

Tests of significance for a group of ranked means are listed by Federer (1955). He discussed the relative merits of the following:

1. Multiple range tests
   The LSD or the multiple t test.
   Student-Newman-Keuls test.
   Duncan's multiple range test.
   Tukey's test based on allowances.
2. Multiple F tests
   Fisher's least significant difference test.
   Duncan's multiple comparisons test.
   Scheffe's test.
3. Tukey's gap, straggler, and variance test.
4. Selection of largest n means from a set of v means.

Examples of some of the more common statistics are given below:

Items	
X	X^2
3	9
6	36
6	36
12	144
9	81
12	144
10	100
9	81
12	144
14	196
17	289
$SX = 110$	$SX^2 = 1\,260$ = Total or gross sum of squares

Mode = 12

Number of items = N = 11

Sum of X's = 110

$$\text{Mean} = \bar{x} = \frac{SX}{N} = \frac{110}{11} = 10$$

Total or gross sum of squares = $SX^2 = 1\,260$

$$\text{Correction term} = \frac{(SX)^2}{N} = \frac{110^2}{11} = \frac{12\,100}{11} = 1\,100$$

$$\text{Net sum of squares} = Sx^2 = SX^2 - \frac{(SX)^2}{N} = 1\,260 - 1\,100 = 160$$

$$\text{Standard deviation} = s = \sqrt{\frac{Sx^2}{N-1}} = \sqrt{\frac{160}{10}} = \sqrt{16} = 4$$

Variance or mean square = $s^2 = 4^2 = 16$

$$\text{Standard deviation of a sample mean} = s_{\bar{x}} = \frac{s}{\sqrt{N}} = \frac{4}{\sqrt{11}} = \frac{4}{3.17} = 1.26$$

$$\text{Coefficient of variation} = CV = \frac{s \times 100}{\bar{x}} = \frac{4 \times 100}{10} = 40 \text{ (in \%)}$$

19. TYPES OF EXPERIMENTAL DESIGNS

A large number of experimental designs are available for use in testing the performance of maize hybrids. A dichotomous classification of designs was prepared by Federer (1955). Since excellent statistics texts are available for a more complete discussion of the subject, only a brief explanation will be given of some common designs, and the advantages and disadvantages of their use. Suggested references include: Federer (1955), Hayes, Immer and Smith (1955), Cochran and Cox (1950), Fisher (1947), Goulden (1939), Homeyer, Clem and Federer (1947), Leonard and Clark (1939), Paterson (1939), Snedecor (1948), and Yates (1937).

Systematic Arrangement

Systematic arrangements are the simplest of all types of experimental designs. They permit growing the entry in the same order in each of several complete replications. This may tend to eliminate errors; permit arrangement of the entries in order of maturity; and simplify planting, note-taking, harvesting, and compilation of data. However, they do not provide for an unbiased, valid estimate of error. Systematic arrangements in many cases also may give misleading information. For example, one entry may yield more than its neighbor because it was always grown on more fertile soil due to a continuous gradient. Several replications of such comparisons will simply multiply the error by the number of replications. These are some of the reasons why this type of design is not very satisfactory.

Complete Randomization

Randomized designs are simple arrangements whereby the entries are grown in a different random order in each of several complete replications. This random order may be obtained by the use of random number tables, pack of cards, numbered discs, or numbered beans.

Randomized designs are widely used by maize investigators. They

are the simplest of all approved types, are easy to lay out, and are applicable for any number of replications, entries, or available area. The data are easily analyzed statistically. Entries with missing plots may be omitted from the analyses and the remaining entries compared without bias. Randomized blocks, however, are not very efficient for comparing large numbers of entries, or where the experimental material or field is quite variable.

Randomized Complete Blocks

Randomization is restricted in randomized complete block design. Hybrid entries are randomly allotted within each stratum or subgroup. The layout might be as follows:

Replication

I	*II*	*III*	*IV*
E	B	D	C
A	C	E	B
B	E	A	D
C	D	B	A
D	A	C	E

Randomized blocks are accurate, flexible, and simple to analyze. Often six replications of a randomized complete block would be as precise as ten replications of a completely randomized performance test. The design is not well adapted to the testing of large numbers of entries, or where the entries or field is quite variable. Methods are available for computing the value of missing plots.

Latin Square

A Latin square is a desirable design for accurate testing of a small number of entries. The replications are arranged in a random order in a square or rectangle with the restriction that each entry occurs but once in each row and column. The following layout is an example of a Latin square:

Replication

I	*II*	*III*	*IV*	*V*
E	B	D	C	A
A	C	E	B	D
B	E	A	D	C
C	D	B	A	E
D	A	C	E	B

A Latin square design is very accurate, statistical analysis is simple, and the error from both rows and columns may be removed or controlled. For practical purposes, the design is limited to small numbers of perhaps four to twelve entries, since the number of replications must equal the number of entries. It is also more difficult to correct for missing plots or values than in a randomized block. Federer (1955) states:

> "that ten replicates of a completely randomized design or six replicates of a randomized complete block design are roughly equivalent to four or five replicates of a Latin square."

Lattice Designs

These designs are very efficient, but are complex and have certain limitations. Entries are arranged in a controlled randomized order which permits correcting the data for variations in soil fertility. Types of design include balanced, partially balanced, rectangular, and cubic lattice.

Number of entries or treatments in balanced lattice designs must be an exact square. The size of the block is the square root of the number of entries. Balanced lattice designs for testing 9, 16, 25, 49, 64, and 81 entries are especially useful. Other lattice designs are available for intermediate numbers of entries. Restrictions on numbers of replications must also be considered.

Many maize workers utilize lattice square designs with $(K+1)/2$ replicates. For example, 49 entries may be compared in a 7×7 lattice square which requires four replications for balance. The plots of each replicate are usually laid out in square formations so that differences in row and column represent fertility variations in two directions at right angles to each other. An example of such a design is shown in Table 41. Lattice square designs are usually much more efficient than randomized blocks. However, number of entries, number of replications, and testing area must fit the design. Use of the Illiac or other digital computer helps tremendously in the computations of these rather complex designs. Such facilities, however, are not available in many countries.

Other Incomplete Blocks

Incomplete block designs usually are arranged in groups smaller than a complete replication. These designs are adaptable for testing from six to two hundred entries. They usually are more accurate than randomized blocks for testing large numbers of entries. All comparisons among pairs of entries or treatments have equal precision. However, they require

TABLE 41. — LATTICE SQUARE DESIGN FOR 49 ENTRIES REQUIRES FOUR REPLICATIONS FOR BALANCE

Replication I

18 143	21 144	19 145	16 146	17 147	20 148	15 149
39 142	42 141	40 140	37 139	38 138	41 137	36 136
11 129	14 130	12 131	9 132	10 133	13 134	8 135
4 128	7 127	5 126	2 125	3 124	6 123	1 122
32 115	35 116	33 117	30 118	31 119	34 120	29 121
46 114	49 113	47 112	44 111	45 110	48 109	43 108
25 101	28 102	26 103	23 104	24 105	27 106	22 107

Replication II

30 243	18 244	12 245	49 246	24 247	6 248	36 249
43 242	31 241	25 240	13 239	37 238	19 237	7 236
17 229	5 230	48 231	29 232	11 233	42 234	23 235
14 228	44 227	38 226	26 225	1 224	32 223	20 222
4 215	41 216	35 217	16 218	47 219	22 220	10 221
27 214	8 213	2 212	39 211	21 210	45 209	33 208
40 201	28 202	15 203	3 204	34 205	9 206	46 207

NOTE : Top number = entry number. Bottom number = plot number.

TABLE 41. — LATTICE SQUARE DESIGN FOR 49 ENTRIES REQUIRES FOUR REPLICATIONS FOR BALANCE
(concluded)

Replication III

40 343	22 344	2 345	20 346	11 347	49 348	31 349
35 342	17 341	46 340	8 339	6 338	37 337	26 336
1 329	39 330	19 331	30 332	28 333	10 334	48 335
13 328	44 327	24 326	42 325	33 324	15 323	4 322
18 315	7 316	29 317	47 318	38 319	27 320	9 321
45 314	34 313	14 312	25 311	16 310	5 309	36 308
23 301	12 302	41 303	3 304	43 305	32 306	21 307

Replication IV

16 443	1 444	42 445	31 446	46 447	27 448	12 449
40 442	25 441	10 440	6 439	21 438	44 437	29 436
32 429	17 430	2 431	47 432	13 433	36 434	28 435
48 428	33 427	18 426	14 425	22 424	3 423	37 422
24 415	9 416	43 417	39 418	5 419	35 420	20 421
8 414	49 413	34 412	23 411	38 410	19 409	4 408
7 401	41 402	26 403	15 404	30 405	11 406	45 407

TABLE 42. — BALANCED DESIGN FOR NINE TREATMENTS IN BLOCKS OF THREE UNITS

Block	Rep. I	Block	Rep. II	Block	Rep. III	Block	Rep. IV
1	1 2 3	4	1 4 7	7	1 8 6	10	1 5 9
2	4 5 6	5	2 5 8	8	4 2 9	11	7 2 6
3	7 8 9	6	3 6 9	9	7 5 3	12	4 8 3

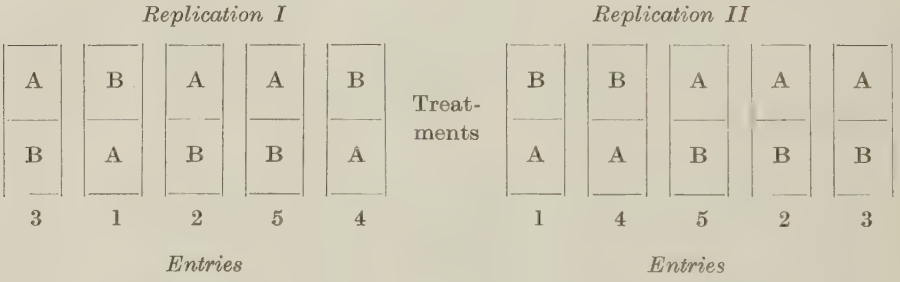
SOURCE: Cochran and Cox, 1950.

more careful planning and time for statistical analysis. Adjustments for missing plots involve rather laborious computations.

Designs may be balanced or partially balanced. Some of the balanced incomplete block designs may be grouped into replications and analyzed as randomized blocks. An example from Cochran and Cox (1950) of a balanced design for nine entries or treatments in three blocks is shown in Table 42.

Split Plots

Split plots are useful for designing experiments involving two or more factors, such as varietal trials combined with studies of rates of planting, dates of planting, or use of fertilizers. The design leads to two or more separate errors which differ in precision. The main plots have a larger error than the subplots. Split plots are very efficient, but are more complex in their design and analysis than randomized blocks. The following is an example of a split plot design:



Factorial Experiments

A factorial design is a complex arrangement in which two or more kinds of treatments are compared in the same experiment. Treatments include all combinations of the factors to be studied. These designs are ideal for studying fertilizer treatments. An example of a 2^3 factorial fertilizer experiment with nitrogen (N), phosphorus (P), and potash (K) would include the following treatment combinations: O, N, P, K, N $\times$ P, N $\times$ K, P $\times$ K, and N $\times$ P $\times$ K. O represents the untreated check treatment.

Factorial designs are efficient and save time and material. They are rather cumbersome and complex, but permit study of the main effects and interactions of treatments. They are very useful: to determine the main effects of each of a number of factors; to study the interactions among several factors or treatments; and to obtain information on which recommendations can be made that apply over a wide range of conditions.

20. PERFORMANCE TRIALS

The importance of utilizing modern field plot techniques and suitable types of experimental design was emphasized in Chapters 18 and 19. Consequently, this chapter will consider the mechanics of conducting performance trials.

Seed Preparation

The maize investigator will need to prepare a planting record which should include the entries to be tested, the pedigree, and the distribution of the plots in the field. This record should also include other pertinent information, such as the experiment number, year, type of experimental material, location of the field, fertilizer treatment, soil type, experimental design, number of entries. number of replications, plot size and shape,

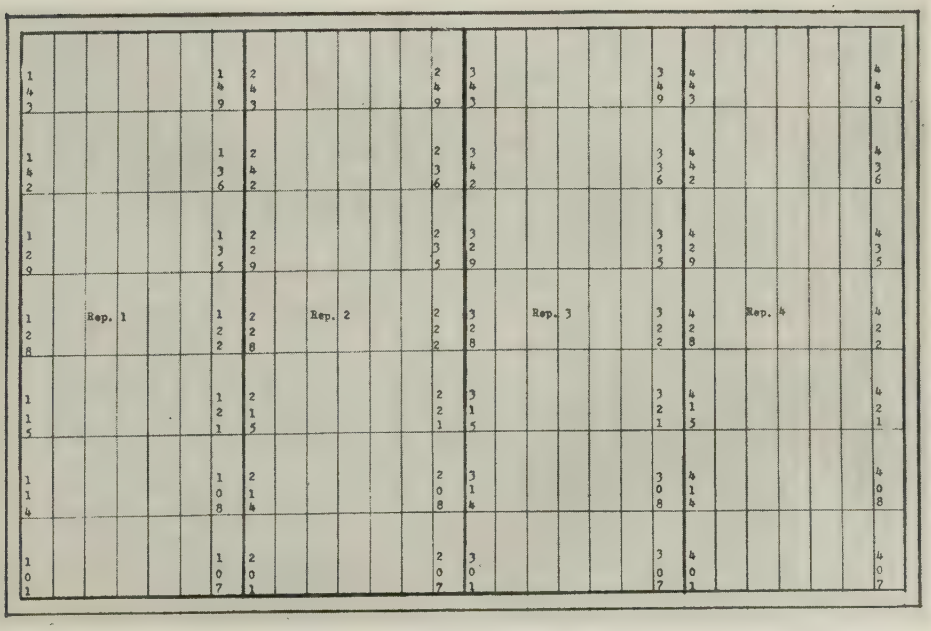


FIGURE 85. - *Planting plan of a performance test using a lattice square experimental design with four replications of 49 entries.*

TABLE 43. — TYPICAL PLANTING RECORD FOR PERFORMANCE TESTS

Experiment 5 *Year* 1954 *Material* Experimental double crosses *Maturity* 800 *Location of field* 751 - Agronomy South Farm, Urbana, Illinois *Fertilizer treatment* 40 lb. of ammonium nitrate per acre applied May 7, 1954 *Soil type* Flanagan silt loam *Previous crop* Red clover *Plowed* Fall *Experimental design* Lattice square *No. of entries* 49 *No. of replications* 4 *Plot size and shape* 2 × 5 hills *Distance between hills* 39.6 in. *Plants per hill* 4 *Date of planting* 5-11-54 *Date of thinning* 6-20-54 *Date of harvesting* 10-20-54

Entry	Pedigree	Code No.	Plot number in replication			
			1	2	3	4
ILL. 21	(Hy2 x 187-2) (WF9 x 38-11)	1	22	24	29	44
ILL. 274-1	(Hy2 x WF9) (Oh7 x 187-2)	2	25	12	45	31
ILL. 972A-1	(Hy2 x L317) (WF9 x Oh7)	3	24	4	4	23
ILL. 1332	(Hy2 x Oh7) (WF9 x 38-11)	4	28	15	22	8
ILL. 1421	(Hy2 x WF9) (P8 x Oh7)	5	26	30	9	19
ILL. 1511	(Hy2 x WF9) (38-11 x L304A)	6	23	48	38	39
ILL. 1570	(Hy2 x Oh41) (WF9 x 38-11)	7	27	36	16	1
ILL. 1759	(WF9 x 38-11) (Oh4C x Oh45)	8	35	13	39	14
ILL. 1764	(Hy2 x WF9) (38-11 x 147)	9	32	6	21	16
ILL. 1767	(Hy2 x Oh45) (WF9 x 38-11)	10	33	21	34	40
ILL. 1777	(Hy2 x WF9) (R114 x R116)	11	29	33	47	6
ILL. 1788	(WF9 x 38-11 (Oh41 x Cl.21E)	12	31	45	2	49
ILL. 1813	(C103 x Oh45) (Hy2 x WF9)	13	34	39	28	33
ILL. 1876	(R.97 x R98) (WF9 x 38-11)	14	30	28	12	25
ILL. 1877	(R99 x R100) (WF9 x 38-11)	15	49	3	23	4
ILL. 1880	(R103 x R104) (WF9 x 38-11)	16	46	18	10	43
ILL. 1884	(C103 x R100) (WF9 x 38-11)	17	47	29	41	30
ILL. 1889	(C103 x Oh45) (38-11 x Oh29)	18	43	44	15	26
ILL. 1890	(C103 x Oh45) (R75 x 38-11)	19	45	37	31	9
ILL. 1896	(R138 x R139) (R140 x R141)	20	48	22	46	21
ILL. 1904	(R81 x R85) (WF9 x 38-11)	21	44	10	7	38
ILL. 1905	(R81 x R120) (WF9 x 38-11)	22	7	20	44	24
ILL. 1906	(Hy2 x WF9) (R81 x R119)	23	4	35	1	11
ILL. 1908	(R154 x R155) (WF9 x 38-11)	24	5	47	26	15
ILL. 1909	(R130 x R151) (WF9 x 38-11)	25	1	40	11	41
ILL. 1910	(R154 x R156) (WF9 x 38-11)	26	3	25	36	3
ILL. 1911	(R130 x R153) (WF9 x 38-11)	27	6	14	20	48
ILL. 1912	(R151 x R156) (WF9 x 38-11)	28	2	2	33	35
ILL. 1913	(R151 x R154) (WF9 x 38-11)	29	21	32	17	36
ILL. 1914	(R153 x R155) (WF9 x 38-11)	30	18	43	32	5
ILL. 1915	(R151 x R155) (WF9 x 38-11)	31	19	41	49	46
ILL. 1916	(R130 x R154) (WF9 x 38-11)	32	15	23	6	29
ILL. 1917	(R153 x R154) (WF9 x 38-11)	33	17	8	24	27
ILL. 1918	(R151 x R153) (WF9 x 38-11)	34	20	5	13	12
ILL. 1919	(R130 x R156) (WF9 x 38-11)	35	16	17	42	20
ILL. 6021	(R75 x R76) (R84 x K4)	36	36	49	8	34
ILL. 6075	(R75 x R83) (R78 x R87)	37	39	38	37	22
AES 801	(WF9 x B7) (B10 x B14)	38	38	26	19	10
AES 802	(Hy x WF9) (38-11 x N6)	39	42	11	30	18
AES 803	(WF9 x 187-2) (N6 x K148)	40	40	1	43	42
AES 805	(C103 x Oh45) (WF9 x 38-11)	41	37	16	3	2
AES 806	(WF9 x Hy) (N6 x N15)	42	41	34	25	45
Ind. 2609	(WF9 x Ind. 38-11) (Oh43 x H14)	43	8	42	5	17
Ind. 9502	(H26 x H27) (H28 x H29)	44	11	27	27	37
Iowa 4615	(WF9 x Hy) (B14 x B36)	45	10	9	14	7
Mo. 4041W	(WhHy x K55) (Wh38-11 x 33-16)	46	14	7	40	47
Ohio 4088	(Oh4C x 0h51A) (Oh28 x 0045)	47	12	19	18	32
Tenn. 3473	(M14×751) (T206×61. 984-8)	48	9	31	35	28
U.S. 13	(Hy x L317) (WF9×38-11)	49	13	46	48	13

spacing of plants and rows, number of plants per hill, and dates of planting, thinning, and harvesting. A suggested planting record for performance trials is shown in Table 43.

A detailed plan of each performance trial should also be prepared (Figure 85). These plans can be prepared on graph paper. Table 41 shows the planting plan of the four replications of material included in Table 43. In each square of Table 41, the upper figures are code numbers representing the hybrid entries. The lower figures identify the plot in the field. For example, as shown in Tables 41 and 43, Illinois 21 (Code 1) was tested in plots 122, 224, 329, and 444.

Seed may be put up in properly labeled paper envelopes ranging from about $2\frac{1}{2}$ inches $\times$ $4\frac{1}{2}$ inches in size to envelopes 4 inches $\times$ 6 inches in size, depending on the amount of seed required for the test. Seed may be counted, weighed, or measured. Sound seed should be selected for the trials. Care must be taken to arrange the numbered envelopes in the proper sequence for planting.

Planting and Thinning

Location of the tests should be representative of the area where the hybrids are to be used by farmers. The land should be prepared in the usual way for maize. The field should be marked in advance in each direction with some type of marker. Seed may be planted with a hand planter equipped with a seed tube and a funnel at the top into which the seed can be dropped (Figure 28, page 76). A carpenter's apron with rounded corners in the pockets is useful for carrying seed and empty packets.

Uniform stands contribute greatly to the accuracy and reliability of performance tests. Consequently, most maize workers plant about double the number of seeds desired for a perfect stand. These plots are thinned to the desired stand after the field has been cultivated one or two times. Care must be taken to prevent losses in a stand due to rodents or careless cultivation.

All of the plots should be labeled to prevent errors. Labeling may be done with wooden stakes driven into the ground or with durable tags or strips of paper. Waterproof paper identification strips may be fastened around the plants with a hand stapler. Tags may be fastened to the plants with a rust-proof wire or strong string.

Efficient Note-Taking

Notes should be taken at appropriate times on all plant or ear characteristics in which the worker is interested. Some notes can be recorded in numerical grades. Grade 3 indicates that the character is about average.

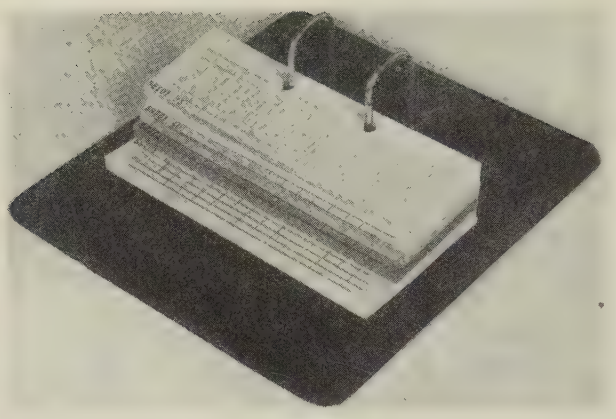


FIGURE 86. - *Cards for recording notes on individual plots facilitate calculation and compiling of data where punch card equipment is not available.*

Grade 2 may be assigned to an entry that is better than average, and grade 4 can be given to one that is poorer than average. Grade 1 may be given to unusually desirable entries, and grade 5 to unusually poor ones. This system of grades is convenient and classifies the material into convenient groups. It is much better adapted for obtaining averages than the use of letters.

Notes may be recorded in notebooks or on cards. Suitable cards for the recording of notes are shown in Figure 86. The use of cards for recording notes on individual plots facilitates the calculating and compiling of data where punchcard equipment is not available. Cards for replication 1 have one line for the recording of data. The cards for replication 2 extend below the cards for replication 1; replication 3 extends below replication 2; and replication 4 extends below replication 3. The cards for replication 4 also contain space for computations. The cards are arranged in the order of the plots in the field.

Harvesting Plots

Harvesting is usually done at the normal time. The ears may be harvested into baskets or bags. Belts, equipped with two hooks, may be worn by the worker to hold the bag for each plot (Figure 87). The worker harvests the ears and drops them into the bag. The bag may be left at the end of the plot and weighed. Notes on dropped ears and erect plants should be obtained during the harvesting. The moisture content of the shelled grain should be determined in order that adjustments can be made in grain yield. The entire plot yield or representative samples from each entry may be shelled with a motor-driven sheller. Data on

dropped ears, number of ears, field weight, shelled grain, and moisture percentage of the grain may be recorded on cards as shown in Figure 86 or on sheets.

Calculating and Compiling Data

After harvesting and shelling the crop, the individual cards from all replications of each entry are grouped together for use in computing acre yield of shelled grain (Table 44). Plot yields of ears are adjusted for differences in shelling percentage, moisture in the grain, and missing hills. Table 45 gives instructions for calculating the data shown in Table 44.

Yields may be adjusted for missing hills. A suggested adjustment of grain yield for missing hills in 10-hill plots is shown in Table 46. This adjustment adds 0.7 of the average hill yield for each missing hill and assumes that 0.3 is made up by the increased yield of surrounding hills. The plot probably should be discarded if more than two or three hills are missing from 10-hill plots.

FIGURE 87. - *Belts, equipped with two hooks, hold the bag used for harvesting of seed or performance trials.*

TABLE 44. — INDIVIDUAL CARDS FROM FOUR REPLICATIONS OF EACH ENTRY GROUPED TOGETHER FOR EASE IN COMPUTING ACRE YIELD OF SHELLED GRAIN

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Plot	Code	Hybrid	Dropped ears	Number of ears	Field weight of ears	Shelled grain	Shelling	Moisture	Dry-matter content	Water-free shelled grain	Grain factor	Missing hills	Adjustments for missing hills	Adjusted field weight	Acre yield of shelled grain (15.5%)
..... Number					.. Pounds ..		..... Percent					No.		Lb.	Bu.
58127	7	1570	0	30	22.4	17.6	78.6	23.8	76.2	59.89	4.96	0		22.4	111.1
58236	7	1570	0	29	22.2	17.3	77.9	25.2	74.8	58.27	4.83	0		22.2	107.2
58316	7	1570	0	31	21.3	16.9	79.3	24.8	75.2	59.63	4.94	0		21.3	105.2
58401	7	1570	0	29	21.8	16.6	76.1	23.1	76.9	58.52	4.87	1	1.078	23.5	114.0
Sum							311.9	96.9							437.5
Mean							77.97	24.2							109.4

NOTE: Plot yields are adjusted for differences in shelling percentage, moisture in grain, and missing hills.

TABLE 45. — INSTRUCTIONS FOR CALCULATION OF DATA FOR SHELLING PERCENTAGE, MOISTURE IN GRAIN, AND ACRE YIELD OF SHELLED GRAIN ADJUSTED TO 15.5 PERCENT MOISTURE

Column	Characteristic	How calculated
1.	Plot number in field	
2.	Code number of entry	Sort cards by code
3.	Hybrid number	
4.	Dropped ears (number)	Record
5.	Number of ears	Record
6.	Field weight of ears (pounds)	Record
7.	Shelled grain (pounds)	Record
8.	Shelling (percent)	$\frac{\text{Column 7}}{\text{Column 6}} \times 100$
9.	Moisture in grain (percent)	Record
10.	Dry-matter content (percent)	100 - moisture percentage in column 9
11.	Water-free shelled grain (percent)	Column 8 x column 10
12.	Grain factor	Column 11 x 8.284 (for 2x5 hill plots, 40'' spacing) $8.284 = \frac{\text{Plots per acre}}{(100\text{-}15.5)\ \text{(Pounds of shelled grain per bushel)}}$ $= \frac{392}{(84.5)\ (56)}$
13.	Missing hills (number)	Record
14.	Adjustment for missing hills	Record appropriate factor
15.	Adjusted field weight (pounds)	Column 6 x column 14
16.	Acre yield of shelled grain adjusted to 15.5% moisture (bushels)	Column 12 x column 15 (in case of missing hills) or Column 12 x column 6 (in case of no missing hills)

TABLE 46. — ADJUSTMENT OF GRAIN YIELD FOR MISSING HILLS IN 10-HILL PLOTS

$$\text{Corrected weight} = \text{Field weight} \times \frac{(\text{Number of hills per plot}) - (0.3 \times \text{number of missing hills per plot})}{(\text{Number of hills per plot}) - (\text{Number of missing hills per plot})}$$

Adjustment adds 0.7 of the average hill yield for each missing hill and assumes that 0.3 is made up by the increased yield of surrounding hills.

Missing hills		Adjustment		
1	=	$\frac{9.7}{9}$		1.078
2	=	$\frac{9.4}{8}$	=	1.175
3	=	$\frac{9.1}{7}$	=	1.300

NOTE: Plots probably should be discarded if more than two or three hills are missing from 10-hill plots.

TABLE 47. — INDIVIDUAL CARDS FROM FOUR REPLICATIONS GROUPED TOGETHER FOR EASE IN CALCULATION OF DATA FOR VARIOUS AGRONOMIC CHARACTERS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
			Lodged plants				Height								
Plot	Code	Days to half-silk	Root	Stalk	Erect plants	Stand	Plant	Ear	Number of ears	Ears per cwt.	Ears per plant	Damaged kernels	Smutted plants	Suckers	Dropped ears
			no.	no.	%	no.	ft.	in.		no.	no.	%	no.	no.	no.
58127	7	76	0	3		30	8.0	41	30	136	1.00	4.0	3	4	0
58236	7	74	2	1		29	8.5	42	29	134	1.00	6.1	0	6	0
58316	7	73	0	2		30	8.0	43	31	131	1.03	7.0	2	3	0
58401	7	74	0	5		30	8.2	41	29	149	.97	5.3	1	4	0
Sum		297	2	11		119	32.7	167	119	550	4.00	22.4	6	17	0
Mean		74							30	138	1.00	5.6	1.5	4	0
Final calculation		74	2%	9%	89	99%	8.2	42		136	1.00	5.6	5%	14%	0%

NOTE: Card for replication 2 extends below card for replication 1, replication 3 extends below replication 2, and replication 4 extends below replication 3. Card for replication 4 also contains space for computations.

Table 47 shows how the individual cards from all replications of one entry are grouped together for use in calculation of data for various agronomic characters other than yield. The instructions for the calculation of these data are given in Table 48.

TABLE 48. — INSTRUCTIONS FOR CALCULATION OF DATA FOR VARIOUS AGRONOMIC CHARACTERS

Column	Characteristic	How calculated
1.	Experiment, maturity, replication, and plot	
2.	Code number of entry	Assemble cards by code
3.	Days to half-silk	Obtain sum and mean
4.	Lodged plants, root (percent)	$\left\{\frac{\text{Sum of column 4}}{\text{Sum of column 7}}\right. \times 100$
5.	Lodged plants, stalk (percent)	$\left\{\frac{\text{Sum of column 5}}{\text{Sum of column 7}}\right. \times 100$
6.	Erect plants (percent)	100-mean of column 5-mean of column 6
7.	Stand (percent)	$\left\{\frac{\text{Sum of column 7}}{\text{Number of plants for perfect stand}}\right. \times 100$
8.	Height, plant (feet)	Obtain sum and mean.
9.	Height, ear (inches)	Obtain sum and mean.
10.	Number of ears	Obtain sum and mean.
11.	Ears per cwt. (number)	$\left\{\frac{\text{Sum of column 10}}{\text{Sum of column 6 of yield cards}}\right. \times 100$
12.	Ears per plant (number)	$\left\{\frac{\text{Sum of column 10}}{\text{Sum of column 7}}\right.$
13.	Damaged kernels (percent)	Obtain sum and mean.
14.	Smutted plants (percent)	$\left\{\frac{\text{Sum of column 14}}{\text{Sum of column 7}}\right. \times 100$
15.	Suckers (percent)	$\left\{\frac{\text{Sum of column 15}}{\text{Sum of column 7}}\right. \times 100$
16.	Dropped ears (percent)	$\left\{\frac{\text{Sum of column 16}}{\text{Sum of column 10}}\right. \times 100$

Use of Electronic Digital Computers

Jacob (1956) at the Illinois Station has pointed out that many data are processed by desk calculating machines. Some agricultural workers use punchcard equipment, but little use is being made of high-speed electronic digital computers. He states that the University of Illinois Illiac high-speed computer can do as much work in one hour as a desk calculator can do in 300 hours.

Jacob (1956) has programmed the Illiac for processing of analysis of variance, analysis of covariance, correlations, regressions, curve fitting, prediction studies, and performance test data involving a wide range of different designs.

Balanced lattice squares with $\frac{k+1}{2}$ replications are very efficient designs for performance tests. Unfortunately these and similar designs

are complex to compute. The Illiac, however, is able to take field weights of unshelled ears from individual plots. By proper programming, these data may be quickly and automatically adjusted for differences in:

1. fertility within the replication;
2. shelling percentage;
3. moisture in the grain;
4. missing hills.

The results are reported in bushels per acre of No. 2 shelled grain at 15.5 percent moisture. All of the pertinent means, sums of squares, variances, and F values are printed out in a standard form as shown in Table 49.

TABLE 49. — PRINT-OUT OF TYPICAL OUTPUT FROM ILLIAC ELECTRONIC DIGITAL COMPUTER

Problem No. Agron - 1690 - Lodged Plants

Treatment means

08.249999999
13.999999999
16.749999995
14.500000002
16.000000003
08.750000002
13.499999995
07.500000007
07.999999993
12.249999991
09.999999998
16.499999998
11.250000002
13.999999990
08.499999996
10.750000007
13.249999998
09.250000006
08.250000008
08.499999996
12.250000000
12.000000002
11.000000004
20.000000004

Analysis of Variance table

Source	DF	Sum of squares	Variance	F
Total	0095	2086.4981040		
Replicate	0003	0024.7500837		
Treatment	0023	1019.0000385	0044.3042256	0002.932
Error	0069	1042.7479819	0015.1124038	
Std dev of mean		01.943733764		
General mean		11.875000000		

Statistical Significance of Results

Replication provides information which permits an estimate of uncontrolled variation known as experimental error. The statistical significance of differences between the entries may be evaluated by the "t" test or "analysis of variance." Procedure may be obtained from many standard statistical texts.

PART V

Seed Production

21. PRODUCTION OF HYBRID SEED

Use of hybrid maize has resulted in the development of a new enterprise: the production, processing, sale, and distribution of hybrid seed. The production of these hybrid seed businesses varies from a few hundred bushels of seed to many thousands of bushels per year. Millions of dollars are invested in land, personnel, plants, and equipment to produce and process this seed. Suggested minimum seed certification standards are given in Chapter 25.

Maintenance of Inbred Lines

The performance of specific hybrids is similar year after year if grown under the same environmental conditions and involving the same pure breeding inbred lines. The maintenance of established inbred lines should be done in a manner to prevent changes in their breeding behavior. These changes in breeding behavior may be due to:

1. delayed segregation;
2. mutation;
3. out-crossing.

In general, heterozygosity of an inbred line is lessened by 50 percent after each generation of self-fertilization. Therefore, some off-type plants of inbred lines will appear as a result of delayed segregation because of the large plant population in a field. Mutation rates vary with different genes, but contribute to changes in breeding behavior. Maize is a naturally cross-fertilized plant, and the pollen is carried considerable distances by wind, insects, birds, etc. Stray pollen, seed mixtures in processing plants, volunteer plants, etc., provide opportunities for out-crossing and are additional sources of contamination.

Balanced amounts of seed of the inbred lines involved in hybrids must be available for commercial use. Most of the hybrids in production are double crosses and involve four parental inbred lines. The seed program will be handicapped if a surplus of seed is available of three inbred lines while only a small quantity is available of the fourth inbred.

Methods of maintaining inbred lines may involve self-pollination.

sib-pollination, or a combination of the two procedures. The maintenance may involve planting parental inbreds ear-to-row, or the ears from individual inbred lines may be composited for increase. Off-type plants from individual ears may be detected and discarded more easily if the material is planted ear-to-row, than from a bulked planting.

Increase of inbred lines by sib-pollination may be done by hand-pollination or in an isolated field. Some workers alternate selfing and sibbing in their maintenance programs. Selfing aids in maintaining the inbred lines in a pure condition. Sibbing, on the other hand, tends to prevent excessive loss of vigor. There is little or no experimental evidence on the ideal population required in a maintenance program. Obviously, such a program should not be limited to only a few ears.

It is relatively easy to detect F_1 crosses between inbred lines in an increase field. Small phenotypic differences can only be detected by individuals who are very familiar with the inbred lines. Bryan and Jugenheimer (1937), and Federer (1941) list various characteristics by which inbred lines may be distinguished. These differences include flower parts such as silk, anther, and glume color. The number and form of tassel branches and pollen shedding are useful characteristics. The height of plants, number of nodes and tillers, amount of chlorophyll, and number and type of leaves are helpful differentiating characteristics. Differences in the ear, such as length, diameter, number of kernel rows, kernel color, indentation, size, quality, row regularity, maturity, disease resistance, etc., are also present among inbred lines. Differences in combining ability can only be detected by actual field testing in hybrid combinations. There is a considerable amount of unpublished evidence to show that combining ability may differ considerably in certain characteristics of some inbred lines.

Inbred Lines Must be Increased

After a hybrid has been thoroughly tested and its desirability ascertained, seed of the parent inbred lines must be increased. Each inbred line may be increased by hand-pollination or by open-pollination in an isolated field. These isolated increase fields should be located at least 80 rods (400 meters) from other maize. A common procedure is to use hand-pollinated seed for planting future isolated inbred increase plots. The seed obtained from these isolated plots may be used for producing seed of foundation single crosses.

Foundation Single Crosses

The second phase in the commercial production of hybrid maize involves crossing the inbred lines. Small amounts of experimental crosses may be obtained by hand-pollination. Larger quantities of seed are pro-

duced by growing the parental inbred strains in alternate blocks in an isolated plot and detasseling, before they have shed any pollen, all of the plants of the strain on which seed is to be produced. In these crossing plots, the parent that furnishes the pollen is called the male or pollen parent, and the one that is detasseled is called the female or seed parent.

The ratio of male to female rows depends primarily on the abundance of pollen produced by the male parent. Inbred lines lack vigor and pollen-producing ability. When they are used to supply the pollen, it is usually best to plant one row of male parent to every two rows of female parent or two rows of male parent to four rows of female parent.

To produce good hybrid seed, the crossing field must be isolated from other maize to avoid contamination from foreign pollen. Fields in which single crosses are being produced should be at least 40 rods (200 meters) from other maize.

All tassels must be removed from the female rows *before* they have shed any pollen. This is necessary in order that the resulting ears on these plants will be a cross between the ear-producing parent and the desired pollen parent. Every seed field should be carefully gone over every day until detasseling is completed. This usually requires about two weeks. Hybrid seed from fields where the detasseling has been carelessly done is almost sure to perform poorly.

Pulling the tassels, usually as soon as they are well out of the " boot," is the most satisfactory method of removal. This probably will be one or two days after they are first visible. If the pulling is done too soon, one or two leaves may be removed with the tassel, or the tassel may break off and not be completely removed. This should be avoided; loss of leaves will reduce the seed yield, and incomplete removal of the tassel necessitates additional labor. When 90 to 95 percent of the tassels have been pulled, it is probably more economical to remove all of those from the remaining plants at one time even though it is necessary to pull several leaves. The loss in yield from pulling leaves on such a small percentage of plants would be more than balanced by the time saved.

Tassels on tillers or suckers should not be overlooked. Tops may be pulled out, regardless of the loss of one or two leaves. The yield will be reduced somewhat if the tillers are removed but it is questionable whether the reduction in yield is of greater value than the additional time required for more careful detasseling.

Since single-cross seed is produced on inbred plants, the acre yields are low, and the kernels are often odd in shape. Care must be taken to prevent injury to the seed during harvesting, drying, shelling, handling, and storage. Most single-cross seed is sold in units of 1,000 viable kernels (MVK). Such seed in the United States usually is priced from $0.50 to $0.60 per MVK.

Double-Cross Seed

Airy (1955) pointed out that the crop risk in producing double-cross seed is reduced by:

"1. selection of high-yielding areas within the state;
2. selection of good fields within a growing area;
3. selection of good farmers;
4. avoidance of droughty or light soil, poorly drained fields, or fields subject to flooding;
5. planting of stands which are adequate but not heavy enough to increase the risk of drought damage;
6. use of a balanced fertilizer program of both starter and broadcast fertilizers;
7. control of insects, especially soil-borne insects, cutworms, and corn borers, through the use of chemicals;
8. emergency use of herbicides, such as 2,4-D, for weed control."

Fields to produce double-cross seed should be isolated 40 rods (200 meters) from other maize. This distance, however, may be modified somewhat depending upon the size of the crossing field and by the planting of border rows of male parent adjacent to the crossing field (See Chapter 25).

When single-cross plants supply the pollen, the seed fields generally are planted in alternate blocks of six rows of female parent to two rows of male parent. Some growers use a ratio of eight rows of female to two rows of male parent. The ears in the male rows are used for feed.

Machines may be used to transport the detasselers (Figure 88). The machine should have a framework high enough to pass over the maize plant without breaking stalks. It has three wheels with steering and power on the single front wheel. Usually it has four forward speeds, and one reverse. Speeds from ¼ to 12 miles per hour permit the driver to select the speed to fit the yield of tassels. The machines come in 4-row, 6-row and 8-row models. Platforms for the detasselers should be adjustable in height and long enough to permit the workers to step back or forward 4 to 5 feet as required. The driver, located behind the detasselers, can inspect their work.

Use of male sterility and pollen restorers will eventually eliminate much of the detasseling presently required in the production of hybrid maize seed. This subject was discussed in Chapter 15.

Commercial Crop

The crop grown from commercial double-cross hybrid seed *should not* be used as seed the following year. Numerous tests in many places have shown that seed from this advanced generation is likely to yield from 10 to 20 percent less grain than that from newly crossed hybrid seed. Some Ohio data on the F_1 and F_2 generations of 10 double crosses show that

FIGURE 88. - *Machines to transport detasselers increase efficiency and reduce labor problems.*

the decreased grain yield varied from 5 to 24 percent, depending upon the specific hybrid. (Richey, Stringfield and Sprague, 1934). On the average, however, the second generation seed yielded 15 percent less than from the newly crossed seed. This is usually about the same as, or a little poorer than, the yield of an open-pollinated variety.

Second generation seed may look fine, germinate well, and produce a field of fine looking plants, but the yield of grain will be disappointing. The original hybrid seed was the F_1 cross between specific parents. Seed from a hybrid field is to a greater or lesser extent inbred. This tends to reduce the yield of the resultant crop.

Wright (1922) pointed out that:

"A random-bred stock derived from n inbred families will have $1/n^{th}$ less superiority over its inbred ancestry than the first cross or a random-bred stock from which the inbred families might have been derived without selection."

Neal (1935) reported that one half, one third, and one fourth of the excess yield of the F_1 generation over the inbred parents will be lost in the F_2 generation when two, three, or four inbred lines, respectively, comprise the parents of the hybrid. He found that the grain yield of the parental inbred lines of the hybrids averaged from 37 percent to 39 percent of that of the F_1 generations, while the F_2 and F_3 generations of single-cross hybrids averaged 70 percent and 76 percent. The F_2 and F_3 generations of three-way crosses averaged respectively 77 percent and 76 percent as much as the F_1 generation. Grain yields of the F_2 generations of double crosses averaged 84 percent of the F_1 generation. His results demonstrated that the dissipation of the excess grain yields of hybrids over the parent maize inbred lines is probably in accord with the simple

genetical rule formulated by Wright. This formula assumes arithmetic gene action.

The adaptation of a hybrid does not depend upon the place where the seed was produced. Unadapted open-pollinated varieties can be brought to an area and by selection over a period of years may be acclimatized to local conditions. This is not true of hybrids. A hybrid is a combination of certain inbred lines. It is the same combination regardless of where it has been produced. The important thing is to know whether the combination is suited to the location and conditions where the crop is to be grown. Therefore, the adaptation of a specific hybrid can be known only after several years of actual test in the farmers' own community. There is some evidence that certain hybrids have a narrower range of adaptation than others.

Seed Requirements

Almost 73 million acres of maize in the United States were planted with hybrid seed in 1955. The United States also exports considerable quantities of hybrid seed to other countries. It appears, therefore, that the United States annually produces at least 12 million bushels of hybrid seed.

Total domestic production of hybrid seed in Europe and the Mediterranean countries increased from 8,755 tons in 1952 to 22,946 tons in 1955. About one third of this seed was produced in the fertile Po river valley of Italy; Yugoslavia, France, Spain, and Egypt also produce considerable quantities of hybrid seed (Table 50).

TABLE 50. — TONS OF MAIZE HYBRID SEED PRODUCED IN EUROPE AND THE MEDITERRANEAN REGION, 1952-1955

Countries	1952	1953	1954	1955
Algeria	—	10	14	16
Austria	—	260	150	350
Belgium	30	2	2	—
Egypt	10	560	1 151	2 030
France	1 700	1 725	2 606	4 050
Greece	130	250	250	230
Israel	—	60	60	465
Italy	5 000	10 000	10 800	7 000
Morocco	6	0	0	5
Netherlands	540	600	178	250
Portugal	211	185	111	205
Spain	1 120	2 420	4 132	2 205
Switzerland	8	17	60	60
Turkey	—	0	75	80
Yugoslavia	—	720	2 000	6 000
Total	*8 755*	*16 809*	*21 589*	*22 946*

SOURCE: Reports o· FAO Hybrid Maize Meetings.

TABLE 51. — ESTIMATED ACREAGES AND YIELDS REQUIRED TO PRODUCE HYBRID SEED MAIZE TO PLANT 25 MILLION ACRES

Year	Kind of field	Acres needed [1]	Estimated yields, bushels	
			Per acre	Total
1954	Inbred lines	48	10	480
1955	Single crosses	2 880	8	23 040
1956	Double-cross seed	138 240	30	4 147 200
1957	Hybrid production (farmer fields)	24 883 200	40	995 328 000

[1] Estimated on the basis that a bushel will plant 6 acres, that seed will be grown on selected desirable fields and that yields of farmers' fields will average 40 bushels an acre.

NOTE: Includes seed and pollen parents.

SOURCE: Jugenheimer, 1955.

Nearly 91 percent of the maize acreage in the United States was planted with hybrid seed in 1956 (Table 4, page 20). About 9 percent of approximately 7¼ million hectares of maize acreage in 17 European and Mediterranean countries was planted with hybrid seed in 1955 (Table 5, page 21).

Jugenheimer (1955) pointed out that enough hybrid seed could be available to plant all of the European maize acreage in a few years. The actual change from open-pollinated varieties to hybrids, however, will depend largely on the superiority of the hybrids, availability of seed, effectiveness of the extension programs, and freedom from excessive government control. Assuming arbitrary rates of planting and yields, it should be possible to start with 48 acres of inbred lines in 1954 and have plenty of double-cross hybrid seed to plant 25 million acres of farm fields in 1957 (Table 51). Purchasing some of the inbred and single-cross seed in the United States should materially hasten the procedure.

22. PROCESSING HYBRID SEED

The processing of hybrid seed has developed into a specialized business involving a series of different operations. Excellent discussions of this subject have been made by Wallace *et al* (1949). and by Airy (1955). Extreme care must be taken to prevent mixtures and damage to the seed during harvesting and processing.

Time and Methods of Harvesting

Seed should be harvested before killing frost in order to assure high germination. Harvesting may begin as soon as the seed is physiologically mature which occurs when the grain contains 30 to 40 percent moisture depending upon hybrid and year. The bulk of the crop may be harvested at 35 to 25 percent moisture. However, harvesting may be started with 40 to 45 percent moisture grain if the crop is immature and the risk from freezing injury is great. Rate of harvesting depends upon the capacity of the dryer.

Airy (1955) pointed out that early harvesting of grain with 30 percent moisture:

1. avoids excessive loss of seed in the field due to mechanical pickers;
2. reduces the risk of delays in harvesting due to rainy weather;
3. reduces the risk of abnormally low temperatures prior to completion of harvesting of all seed;
4. prevents further development of ear rot fungi;
5. stops insect damage from corn borers and ear worms;
6. avoids severe shelling losses from handling of low moisture grain.

Variables influencing the amount of injury to germination from freezing include:

1. temperature;
2. variety of seed;
3. duration of exposure;
4. husk protection;
5. physiological maturity of seed;
6. rate of drying after freezing (Airy, 1955).

Harvesting the seed when fully mature results in:

1. improved appearance of seed;
2. stronger emergence of seedlings under adverse growing conditions;
3. greater resistance to mechanical injury from handling in processing plants;
4. reduced susceptibility to injury from higher drying temperatures;
5. increased yield (Airy, 1955).

In the United States most of the seed is harvested with machinery. The two-row picker mounted on the tractor harvests two rows at a time without disturbing the crop on either side. A mounted. two-row picker permits leaving the male rows in the field until dry enough to crib without drying. Usually only one hybrid is harvested at a time and the seed is delivered to the plant.

Airy (1955) suggested that mechanical damage to the seed by the picker may be reduced by:

"1. driving slowly;
2. driving squarely on the row;
3. using snapping rolls that are fairly new;
4. having the rolls set closely together;
5. removing pegs from the snapping rolls;
6. releasing the ear retainer pressure on the husking roll."

Husking and Sorting

The harvested crop is transported to the processing plant where the seed is unloaded onto a moving belt and carried into the seed house. Most producers leave some husks on the ears to lessen damage to the seed during the handling process. These husks are removed after the crop has been transported to the processing plant. Removal of husks may be done by hand or by a number of different makes and arrangements of mechanical huskers. The husker unit needs to be adjusted for different seed parents and hourly changes in moisture content of the grain.

In a typical plant, the ears go from the husking rolls to a sorting belt or tables. The workmen may stand on one or both sides of the belt and discard the undesirable ears. Provision should also be made for discarding shelled grain. The crop, free of husks, silks, and shelled grain, may be delivered by belt or elevator to the drying bins. In some cases, producers may do the sorting before the crop is brought to the plant. Dual function of the conveyor belt discards the cull ears on the lower belt while good ears are carried off on the top belt.

Drying

If the seed contains more than 12 to 13 percent moisture, some provision should be made for removing excessive moisture. Drying requires a considerable investment in drying bins, heating units, fans, and convey-

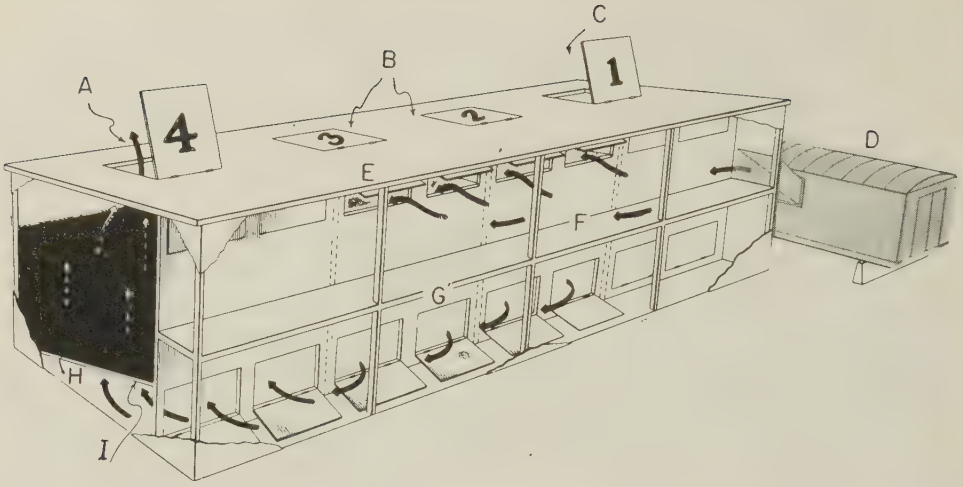


FIGURE 89. - *Dryers efficiently remove excess moisture from the seed.*

A. *Moisture-laden air is exhausted here*
B. *Heated air passes through grain in bins 2 and 3*
C. *Bin no. 1 can be emptied and refilled during drying operation with air doors closed*
D. *Campbell seed corn dryer*
E. *Doors closed on bins 2 and 3*
F. *Heated air duct*
G. *Transfer air duct*
H. *Air passes up through grain in bin 4*
I. *Slatted floor.*

ing equipment for filling and emptying bins. The Campbell Heating Company, Des Moines, Iowa, has designed drying systems for processing plants throughout the world. They have also developed portable dryers which include an oil- or gas-fired furnace and fan mounted on a truck chassis. These portable dryers can be moved from building to building. Shelled grain drying equipment is also available in both batch and continuous flow types, in capacities of 50 to 1,000 bushels per hour, using natural gas, liquid petroleum or oil.

Most drying bins are provided with a latticed bottom. The slatted floor may be sloped to one side of the bin to aid in emptying the seed. The heated air usually is delivered to the under side of the slatted floor. Since the sides of the bin are air tight, the air is forced up through the bin of grain which may be 7 to 10 feet in depth. Some seed houses are arranged to permit reversing the direction of the heated air through the ears (Figure 89).

The furnace may use oil, gas, or coal. The air is forced through the seed ears by a multivane fan. Airy (1955) states that the air volume should be based on 13 cubic feet per minute per bushel with air velocities through the bin of 50 cubic feet per square foot of bin area with partly dry seed ears, and 100 cubic feet per square foot of bin area with high moisture ears.

Seed with high moisture content should be dried at temperatures not higher than 105° F. to 110° F. in order not to injure the germination. Temperature should be controlled by a reliable thermostat. Most drying units operate 24 hours a day, 7 days a week, during the processing season.

Wallace *et al* (1949) stated that seed ears delivered to the drying bin with 35 percent moisture and exposed to moving air at a temperature of 107° F. require from 72 to 90 hours drying time. This should reduce the moisture content of the grain to approximately 13 percent. Seed ears with about 25 percent moisture may be reduced to 13 percent moisture in 50 to 60 hours. Variables within the drying process include humidity in the air and the amount of air moved through a given quantity of seed ears. Air temperatures as high as 115° F. may be used with mature seed of 25 percent moisture or less and when the seed parent is not susceptible to injury by high temperatures.

Shelling, Cleaning, and Sizing

Airy (1955) pointed out that the shelling, cleaning, and sizing of maize seed are necessary to prepare a uniform, high quality product, satisfactory in appearance and easily planted by the farmer customer in existing equipment. He stated that only about 65 to 75 percent of the crop delivered from the field is of salable seed sizes. About 15 percent of the original crop is lost in sorting, handling, shattering, and drying. The ratio of bushels of sized seed to bushels of shelled grain ranges from 78 to 88 percent. His estimates of normal cleaning and sizing losses are: air cleaning, 1 percent; tips, 4 percent; short kernels removed, 9 percent: and gravity machine rejection, 3 percent. These losses vary according to hybrids, growing areas, and seasons.

Most of the hybrid seed is shelled by machinery. The cylinder type sheller is convenient and has high capacity. Care must be taken to prevent injury to the grain. Consequently, some shellers have been modified to use special rubber coverings on the cylinder. Usually, these shellers are operated at a slower speed for seed than for market corn. Shelling should be done when the seed contains 12 to 14 percent moisture.

Airy (1955) reported cold test germinations after four methods of shelling:

1. hand shelling;
2. one-hole hand spring sheller;
3. plant spring sheller;
4. cylinder sheller.

Cold test germinations for untreated seed were 77, 71, 71, and 63, and for treated seed 86, 81, 80, and 77, respectively. A spring sheller, operated at speeds of 205, 315, and 425 r.p.m., gave seed with cold test

germinations of 77, 74, and 68, respectively. A cylinder sheller, operated at speeds of 240, 360, 480, 600, and 720 r.p.m., gave cold test germinations of 74, 66, 61, 59, and 50, for untreated seed, and 79, 79, 77, 79, and 64, for treated seed with both given in order of increasing sheller speed.

The seed is usually cleaned with special machines. Most seed is separated into various lots by mechanical means depending on width, thickness, and length of kernel. The sizing operation is usually organized to obtain three or four sizes of flat kernels and three sizes of round kernels. Large flat kernels are regular in shape and of uniform thickness, width, and length; medium flat kernels are smaller than the large flat kernels but are similar in shape; small flat kernels are still smaller. Kernels irregular in shape are popularly termed round kernels. Three grades of rounds may be obtained, depending upon the relative size of the kernels. The medium flat kernels are usually the most popular size. The percentage of flat kernels may be increased by providing plenty of pollen and by utilizing a seed parent with long ears. Seed houses should be equipped with magnetic devices that will remove nails, metal, etc., from the grain prior to sizing.

Calibration for Planters

The farmer is interested in obtaining the desired optimum stand of plants. Consequently, the seed industry has devoted considerable effort to sizing of seed and use of recommended planter plates. Different plates are required for planting the various sizes of seed. The seed industry recommends the proper planter plates to be used for the different seed lots. This information should be stamped on the label of the seed bag.

Seed Treatment

Much of the hybrid seed in the United States is treated with a chemical compound. These fungicides are used to protect the seed between planting and germination. The maize seed is alkaline in reaction after it absorbs water but before sprouting. This makes it a good culture medium for various fungi present in the soil. Most of these diseases thrive readily when the soil is wet and the temperature is between 40° and 50° F. Most dent seeds do not germinate well when the soil temperatures are below 55° F. The fungicide provides a protecting film around the seed which helps to retard the growth of molds and diseases until conditions are satisfactory for germination. The chemical reaction of the kernel changes from alkaline to acid soon after the kernel germinates.

TABLE 52. — INCREASE IN STAND AND YIELD OF MAIZE RESULTING FROM SEED TREATMENT AS AFFECTED BY SEED CONDITION, AND KIND AND RATE OF TREATMENT

Seed condition code	Seed treatment	Rate	Stand		Acre yield	
			Actual	Increase over untreated	Actual	Increase over untreated
		Oz./bu.	..... Percent		..... Bushels	
A	None	—	84.1	—	87.1	—
(Mature processed)	Arasan SF[a]	1/2	91.6	7.5	94.3	7.2
	Arasan SF[a]	1	92.0	7.9	95.9	8.8
	Spergon DDT-SL[b]	1/2	89.0	4.9	93.1	6.0
	Spergon DDT-SL[b]	1	89.6	5.5	93.7	6.6
	Phygon XL-DDT[c]	1/2	89.8	5.7	94.0	6.9
	Average increase		—	6.3	—	7.1
B	None	—	80.9	—	84.7	—
(Mature pericarps artificially injured)	Arasan SF	1/2	92.2	11.3	94.8	10.1
	Arasan SF	1	93.8	12.9	96.3	11.6
	Spergon DDT-SL	1/2	87.7	6.8	92.3	7.6
	Spergon DDT-SL	1	89.7	8.8	94.1	9.4
	Phygon XL-DDT	1/2	92.0	11.1	93.2	8.5
	Average increase		—	10.2	—	9.4
C	None	—	93.6	—	96.9	—
(Mature sound pericarps)	Arasan SF	1/2	94.9	1.3	97.7	0.8
	Arasan SF	1	95.1	1.5	97.6	0.7
	Spergon DDT-SL	1/2	93.9	0.3	96.6	— 0.3
	Spergon DDT-SL	1	94.3	0.7	98.2	1.3
	Phygon XL-DDT	1/2	94.0	0.4	96.2	— 0.7
	Average increase		—	0.8	—	0.4
D	None	—	81.8	—	86.5	—
(Immature sound pericarps)	Arasan SF	1/2	91.6	9.8	96.2	9.7
	Arasan SF	1	91.6	9.8	95.4	8.9
	Spergon DDT-SL	1/2	88.7	6.9	91.5	5.0
	Spergon DDT-SL	1	90.4	8.6	93.1	6.6
	Phygon XL-DDT	1/2	90.3	8.5	93.1	6.6
	Average increase		—	8.7	—	7.4
L.S.D., 5 percent level				3.2		3.3

[a] Thiram 75 percent. — [b] Chloranil 92 percent plus DDT 3 percent. — [c] 2,3-dichloro, 1,4-naphthoquinone 50 percent plus DDT 3 percent.

NOTE: Average Time, Planting to Emergence, 9 Days, 2 Hybrids, Urbana, Illinois, 1949-51, incl.

SOURCE: Koehler, 1954.

Mature seed with sound pericarps is not benefited greatly by seed treatment. The increase in stand and yield resulting from seed treatment is shown in Table 52. The seed containing pericarp injuries responded more to seed treatment than hand-picked and carefully handled seed. Other variables affecting the results of maize seed treatment include age of seed, resistance to seedling blight, frost damage, and method of drying (Koehler, 1954).

According to Airy (1955), organic fungicides containing thiram, phygon, spergon, or captan, may be used with little risk of seed damage by heavy rates of treatment and give effective control of soil pathogens and some seedling diseases. These materials may be applied in dust or slurry form. Recommended rates of application vary from 0.5 to 1.0 ounces of active ingredient per bushel. The slurry application involves a mixture of the fungicide in water. The recommended dosage is 1 pound of fungicide per gallon of water with 2.3 cubic centimeters of the slurry distributed over 1 pound of seed to give the 0.5 ounce rate.

The seed industry desires a fungicide that is not poisonous or irritating to workmen and livestock. Representatives of manufacturers of spergon and captan claim that these substances are not poisonous to livestock. The slurry application eliminates irritating dusts. Care should be taken in the use of all chemical treatments.

Airy (1955) discusses the various machines that may be used for applying the slurry fungicides which:

> "include the original by DuPont; modifications of the original marketed by Ben Gustafson and Son Manufacturing Company, Fargo, North Dakota, and Calkins Manufacturing Company, Spokane, Washington; a semi-automatic batch treater; a continuous-flow treater with slurry sprayed on the seed; a continuous-flow slurry treater without spray by Superior Grain Separator Company, Hopkins, Minnesota; a continuous-flow slurry treater without spray by Pioneer Hi-Bred Corn Company, Des Moines, Iowa; and a continuous-flow treater with fungicide, water spray, and grain introduced simultaneously into a rotating drum by Green Giant Company, LeSueur, Minnesota."

Grain storage pests may be controlled with lindane and pyrethrin powders. Dieldrin aids in the control of soil-borne insects. Dieldrin may be applied to the seed, mixed with the fertilizer, or sprayed on the soil.

Germination Tests

Samples of seed should be taken at regular intervals during the processing procedure. These samples should be checked for planting accuracy, appearance of adequate seed treatment, and for germination tests.

Germination tests include "warm" and "cold" tests. The warm test germination measures natural viability of the seed. The test is con-

ducted with a temperature of about 80° F., and with high relative humidity. The seed is placed on a blotter, cloth, or in wet sand or soil. The percentage of germination is usually recorded on the bag label.

The cold test is similar to the warm test except that it is conducted at a lower temperature. This is a laboratory test to simulate adverse field conditions. Rinke (1954) pointed out that the principal factors affecting cold testing results include:

1. disease organisms present in the soil;
2. amount of water used;
3. temperatures;
4. length of exposure;
5. environment of seed production;
6. maturity of seed;
7. mechanical damage to seed;
8. seed treatment.

Varying any of these factors may affect the results of the tests. Procedures involved in conducting cold tests were discussed in Chapter 10.

Tetrazolium stain has been used both in Europe and the United States for a quick estimation of seed germination. This procedure involves soaking the seeds in lukewarm water for several hours after which the kernels are split longitudinally and perpendicularly to the germ side. The split seeds are placed in a weak solution of tetrazolium chloride. After two hours, the seeds with living germs turn a pink color while the dead kernels remain colorless. This test is especially useful to detect freezing injury, or when a rapid germination evaluation is required.

Weighing, Bagging, Tagging, and Sewing

Hybrid seed in the United States usually is sold in one-bushel bags. Bags may be made of cloth or special moisture-resistant paper. Various sizes of mechanical equipment are available for filling, weighing, and closing the bags. Most bags are closed by machine sewing. Each bag of seed should be labeled with a tag carrying information to meet all seed laws.

Seed Storage

All seed should be stored in a dry, cool place free from rodents and storage insects (Figure 90). Seed may be stored in unheated warehouses without damage from winter temperatures if the moisture content of the grain is 12 percent or less. Some provision should be made to prevent the bags from absorbing moisture from the floor or in other ways. Some fumigants injure germination.

FIGURE 90. - *Seed should be stored in a dry, cool place, free from rodents and insects.*

(Courtesy, B. Koehler)

Results of extensive storage tests with maize seed were reported by Sayre (1940). Some of Sayre's experiments differ from others in that the seed was sealed hermetically in glass tubes or in tin cans. Seed exposed to the air may absorb or lose moisture depending on the relative dryness of the air.

Sayre stored seed at several different temperatures. Germinations were determined from year to year by planting the seed in the soil at the normal planting time. He studied the effect of moisture content of the seed and the temperature of storage on the germination of maize seed stored for different lengths of time. The germination of maize seed adjusted to different moisture contents and stored at room temperature for 13 years is shown graphically in Figure 91. Seed with 18 percent moisture was dead in one or two years. Seed with 14 percent moisture showed a decrease in germination that would be serious for seed purposes after three or four years.

Seed with 7.5 percent to 11 percent moisture germinated satisfactorily after seven years. Seed with 5 percent moisture content germinated 80 percent after 13 years of storage.

Germination of maize seed with 11.2 percent moisture stored under different conditions is shown in Figure 92. These data show that seed stored at the higher temperatures would not be satisfactory for planting after a few years. The same seed stored at a low temperature showed no decreased germinating ability after 12 years of storage. Seed in tubes open to the air and stored at 37° F. germinated poorly because it had absorbed water from the air in the moist storage room.

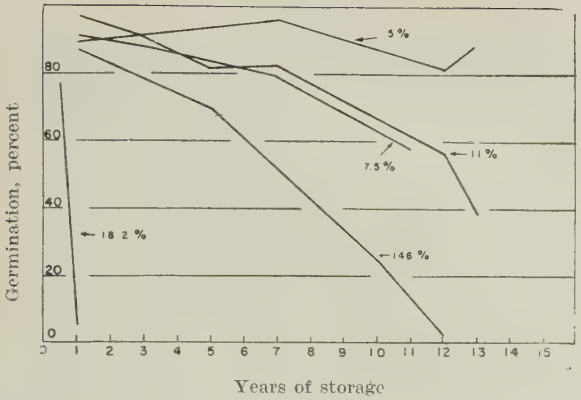
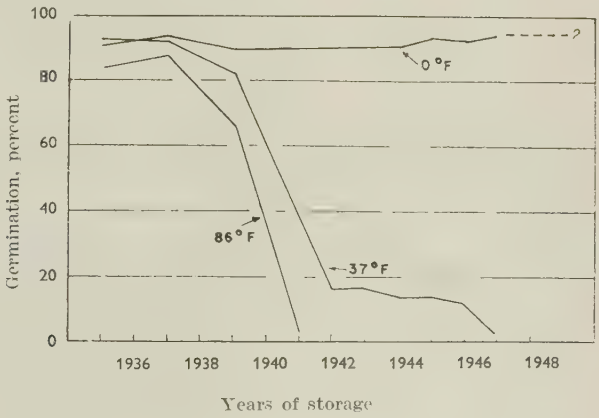


FIGURE 91. - *Germination of maize seed adjusted to different moisture contents (indicated by percentages on the graph) and stored at room temperature.*

(Courtesy, J. D. Sayre)



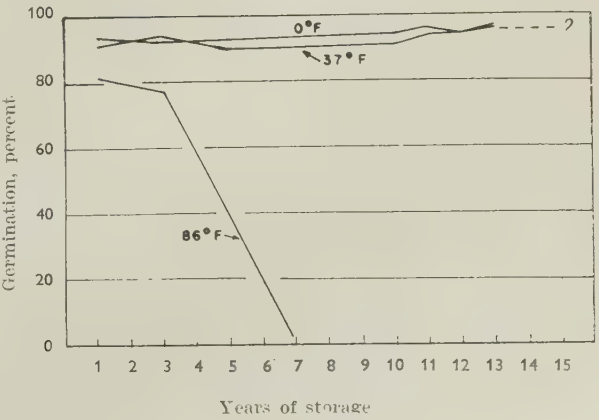


FIGURE 92. – *Germination of maize seeds with 11.2 percent moisture and stored under different conditions:* (above) *seeds open to the air and* (below) *seeds sealed in glass tubes.*

(Courtesy, J. D. Sayre).

Sayre concluded that:

"Seed corn stored in sealed glass tubes under favorable conditions retained its viability better than seed corn stored similarly, but open to the air. Seed corn containing more than 12 percent moisture lost its viability rather rapidly regardless of other storage conditions. Lower moisture contents were increasingly favorable to longevity. Storage temperatures of 70° F. or higher were detrimental to longevity, whereas those of freezing or below were all favorable to longevity.

Seed dried to 5 to 8 percent moisture sealed in air and stored at temperatures of 70° F. or lower retained its viability throughout the longest experiments, 13 years, with every indication that it would live much longer. Storage in carbon dioxide or nitrogen had little or no influence on longevity, but storage in oxygen shortened it. Airtight containers prolong the life of seeds by preventing fluctuations in moisture content with changes in air humidity. Seed corn can be carried over a number of years by drying it to 5 to 8 percent moisture and storing it in airtight containers. It should be stored at a uniform temperature. If dry, low temperature storage is available, it can be kept for many years without losing its vitality."

Carry-Over Seed

Carry-over seed is that portion of the crop that is retained until it is more than one year old. Seed producers cannot predict with accuracy the yield of seed to be obtained each year. Seed yields vary from year to year depending upon climatic and other factors. These seasonal variations in yields may cause a surplus of seed in some years and a short supply in others. As a result, the producer must usually plan to grow a somewhat larger acreage to assure his customers of seed each year. Carry-over seed tends to insure against crop shortages.

Inbred seed and single-cross seed may be stored for several years, if necessary or desirable. Low temperatures and low moisture content of the grain is necessary for storing maize seed for many years. Surplus double-cross seed is usually stored a year or less before it is used. Carry-over seed is satisfactory for later use if germination tests indicate that the seed is still viable.

23. SELLING AND DISTRIBUTING HYBRID SEED

Many potential farmer customers are skeptical of the merits of maize hybrids. Three important factors which aid the distribution and use of hybrid seed include:

1. farmer education;
2. freedom from excessive controls;
3. methods of selling.

Farmer Education

Jenkins (1953) in the Report of the Sixth FAO Hybrid Maize Meeting pointed out that:

"Farmer education in the use and advantages of hybrid maize is essential to its expanded utilization. If farmer education is to be most effective it should comprise a well-rounded program covering such phases as:

1. good seedbed preparation;
2. use of adapted hybrids;
3. proper density and spacing of plants;
4. proper use of available fertilizers;
5. shallow cultivation to avoid root damage;
6. efficient harvesting procedures;
7. good storage to avoid losses.

In the early stages of the work most of the responsibility for farmer education of necessity falls on official agencies. With proper organization, an increasing amount of assistance can be obtained from the commercial producers of hybrid seed maize as the program advances. In the United States, a major portion of the job of farmer education was done by the hybrid seed maize companies in connection with their sale of seed. Many of the seed maize producers put on very aggressive sales programs, and the educational features of these programs had an important and substantial effect in the over-all education of their farmer customers.

The educational programs of commercial seedsmen are a direct result of their competition for seed sales. In European countries where competition for seed sales has been greatly reduced or eliminated there has also been a much smaller development of the educational features associated with competitive sales. As a result, a much heavier burden of responsibility for farmer education is placed on governmental agencies."

Demonstration plots are effective aids in getting farmers to try hybrids. A selected, adapted hybrid should be compared with a local open-pollinated variety or unadapted hybrid in strips across farmers' fields.

Freedom from Excessive Controls

Jenkins (1953) believes that:

"The primary problem now affecting the future expansion of hybrid maize in several European countries is the development of a commercial hybrid maize industry capable of serving the seed needs of the country. The hybrid seed maize industry of the United States developed under free competition. It has served the country in a remarkable manner, but there is no denying that a number of faults and abuses have occurred. Free competition of the kind that developed the hybrid seed maize industry of the United States does not now exist in any European country. Consequently, the industry is developing in quite a different manner than it did in the United States and at a much slower rate.

Restrictions on the production of hybrid maize as they exist in Europe are of two kinds:

1. government regulations;
2. cartels and monopolies.

It has been stated that 'competition is the life of trade' and certainly competition for markets is a very strong force favoring the development of sound growth. A certain amount of government regulation of the hybrid maize seed industry is necessary to insure high quality seed and protect the consumer from unscrupulous seedsmen. When regulation is too strict, however, it tends to strangle the industry and retard development. Cartel arrangements and monopolies also tend to slow up progress. They retard the development of improved hybrids and remove the incentive for aggressive sales campaigns. Italy and the Netherlands seem to have been more successful in the development of hybrid seed maize industries than other European countries. In each of these countries the industry has developed under more competitive conditions and is being less hedged about by restrictions that in the remaining areas.

The production of hybrid seed maize in the United States has been subject to relatively little regulation. Wisconsin and a limited number of other States have required that hybrid seed maize be certified before it is offered for sale. Some other States require a license and issue licenses only for the sale of hybrids recommended for planting within the state. Aside from these regulations in a few States, the only essential regulation has been that seed offered for sale as hybrid seed must meet the legal definition of hybrid maize seed; that is, it must be the first generation of a cross involving inbred lines of maize.

This freedom of operation that has existed in the United States has resulted in a number of abuses. One of these abuses is the practice of assigning numerous trade names to standard hybrids. The freedom has also resulted in numerous benefits. One of the most important of these benefits is the extensive education of growers accomplished by seedsmen in their competitive efforts to sell seed.

In an effort to curtail the abuses that have developed in America, some European countries have so regulated and restricted the production of hybrid maize seed as greatly to retard seed production. When regulation goes this far, the cure is worse than the disease.

The other restriction on production that has developed in some European countries is the development of monopolies and the restriction of seed production to one or a few favored companies. Lack of competition removes the primary incentive for seed sales. When there is no competition the seed producer is inclined to sit in his office and wait for customers instead of going out after the business. He produces only the seed he is certain he can sell and has no incentive to improve seed quality, produce better hybrids or engage in farmer education in order to widen his market.....

I consider this lack of free enterprise as one of the main problems now retarding the expansion of hybrid maize in several European countries. This opinion is supported by the relative rate of expansion in the different European countries. The Netherlands has the fewest restrictions and although a small country the rate of expansion has been greatest. Italy has expanded the use of hybrid maize very rapidly and has relatively few restrictions on seed production other than the requirement that all seed must be sold through one organization and at standard prices. France has rather stringent regulations on the production and sale of hybrid seed maize. These regulations practically prohibit seed production of closed pedigree hybrids. Seed producers must be members of an association of maize producers which regulates seed production and prices. The result is greatly to reduce competition among producers and essentially eliminate their interest in expenditures for consumer education.

International trade in hybrid seed maize would be greatly facilitated by the development of uniform standards of quality. Some start already has been made in the development of a uniform set of certification standards. The essential requirements of an adequate international certification procedure are:

1. a definite set of uniform standards agreed to by all co-operating countries;
2. efficient and impartial administration of these standards.

If standards can be developed so that seed can be offered for sale on the basis of these guaranteed standards, there will be much less hesitation to purchase seed across international borders than at present.

The efficient production of hybrid seed maize requires that the seed be produced in the areas best adapted to production. The most efficient production areas are those where large yields of high quality seed can be obtained and where a minimum of artificial drying is required. This often means that seed is most efficiently produced in areas with a slightly longer growing season than that where the crop is to be used commercially.

American hybrids have given very good results in most of the areas in Europe suited to the growing of dent maize. Even in these areas, however, the American hybrids are out of the general environment for which they were developed. They must be viewed, therefore, as temporary expedients and replaced as rapidly as possible with European hybrids developed to fit local conditions. Only when this has been accomplished can hybrid maize achieve its fullest usefulness in Europe.

Substantial progress already has been made in the development of European and European-American hybrids. Breeding work is in progress in several countries and many European lines are in the process of being evaluated in hybrids. The six international Hybrid Maize Meetings sponsored by FAO have contributed greatly in welding this work into a co-operative program designed to serve European requirements with maximum effectiveness. It is hoped that these meetings will be continued as American experience emphasizes the extreme importance of co-operative effort in both the breeding and testing programs. The co-ordinated work now in progress soon should produce new hybrids for distribution to farmers in several European countries."

Methods of Selling

Several methods are used for selling and distributing hybrid seed. Direct sales by farm dealers are the most popular method of selling hybrid seed in the United States. The seed company usually engages prominent farmers in various communities to explain its product and to solicit business.

Airy (1955) explained that the local salesman:

1. calls on his farmer neighbor;
2. solicits his business;
3. writes up an order;
4. receives the bagged seed in the spring on consignment;
5. arranges for the customer to pick up the seed at the salesman's place of business or some other designated location;
6. completes the actual sale and collects for the seed when the farmer receives it;
7. gives service to the customer as is needed throughout the growing season.

The salesman is usually paid a commission which is based on the number of bushels of seed sold.

Some seed is sold in the United States by seed dealers and elevator operators from stocks in their place of business. Some hybrid seed is sold direct by mail. Considerable quantities of seed in some European, African, and South American countries are sold directly by the Government or government agencies. Most of the seed in Italy and France is sold through co-operatives.

Seed sales are influenced considerably by the personality of the salesman. His appearance, voice and conversation, manners and habits, and general attitude may influence the volume of his sales.

The salesman should have a general knowledge of the potential customer. He should know what types of maize the customer prefers. He may also appeal to the preferences and wishes of the customer. Such appeals to the customer's desires include the desire for monetary gain, the desire for security, and imitation of respectable people in the neighborhood.

A successful salesman must have a good knowledge of the product he hopes to sell. Obviously, he needs to know the advantages of his own hybrids and the disadvantages of his competitors' hybrids. He also should be prepared to answer possible criticism of his own hybrids. A general knowledge of his company and its activities is also helpful. He might emphasize the modern production and processing methods, and also point out special services that are available from his organization.

24. FOUNDATION SEED STOCK ORGANIZATIONS

Much of the success of a hybrid maize program is dependent upon a stable supply of pure seed of foundation inbred lines and single crosses.

Purpose

Ingersoll, at the Seventh FAO Hybrid Maize Meeting in Belgrade, Yugoslavia, pointed out that all successful seedsmen should be concerned about the availability of high-quality foundation seed. This seed must be on hand at planting time each year or the entire project will fail. A stable seed supply depends either upon the producer's growing all of the single crosses necessary for his own use or depending upon a foundation seed stock organization for his supply.

A hybrid seed producer interested in producing his own single-cross seed is presented with many problems. The production of only three hybrids might involve the maintenance of twelve inbred lines and the production of seed of six single crosses. Such a program requires extensive hand pollination of inbred lines and several isolated fields for single-cross production. Such programs usually result in excessive supplies of some single crosses and inadequate amounts of others. A seedsman should have at least one year's supply of foundation seed on hand in order to provide protection against crop failure. Additional problems include obtaining suitable isolated fields and producing high quality, pure seed in these small plots.

Types of Organizations

Foundation seed may be produced by agricultural experiment stations, government agencies, crop improvement associations, co-operatives, and private individuals or organizations. Each type of organization may be operated successfully.

In the United States, many agricultural experiment stations have sponsored co-operative organizations of seed producers for the produc-

tion of foundation seed. The agricultural experiment station usually agrees to:

1. increase and make available certified foundation seed of improved varieties of field crops;
2. maintain a supply of certified foundation seed of previously released varieties of field crops;
3. make available to the seed stock organization a portion of the foundation seed at a fair price;
4. direct the distribution of seed produced from foundation seed and increased by the agricultural experiment station and by the foundation seed stock organization.

The co-operative seed stock organization usually agrees to:

1. increase for distribution the varieties approved by the agricultural experiment station;
2. plant the seed on land owned or controlled by the association according to the recommendations of the agricultural experiment station;
3. select suitable co-operators and fields; supervise the planting, pay for certification; supervise the removal of objectional weeds and mixtures; oversee the detasseling, roguing, harvesting and processing of the seed;
4. apply for certification of all seed;
5. dispose of any seed failing to meet certification requirements as directed by the experiment station;
6. distribute the seed produced from the foundation seed to qualified producers as directed by the experiment station;
7. follow the price pattern suggested by the station.

Ingersoll (Seventh FAO Hybrid Maize Meeting) explained that a typical foundation seed stock organization may offer seed of 150 different single crosses. This may require the maintenance of approximately 100 and the increase of about 65 inbred lines. This maintenance and increase is produced by hand-pollination, and in isolated fields. The hand-pollination field may be from 10 to 20 acres in size. It is used for the maintenance of all inbred lines, and for increasing the inbreds for use as pollinators in the single-cross production fields.

The production of 150 single crosses might require approximately 40 isolated fields varying in size from 2 to 100 acres, depending upon the demand for the seed. The planting dates and rates, roguing, detasseling, harvesting, and processing of the seed of inbred lines and single crosses must be done even more carefully than for double-cross seed. Obviously, the production and sales program must be co-ordinated.

Jenkins, at the Eighth FAO Hybrid Maize Meeting at Wageningen, Netherlands, pointed out that a good foundation seed organization required adequate technical guidance, proper equipment for seed processing, and storage facilities to carry over an adequate reserve. He stressed that the breeding work, foundation seed production, and certification should be conducted by independent agencies.

Schad, at the Sixth FAO Hybrid Maize Meeting, Lisbon, Portugal, explained that a national maize seed growers federation had been organized in France for the inspection and certification of crops. This federation has been assigned the propagation of inbred lines and single crosses for the protection of hybrid maize growers in France. At the beginning of each growing season the federation distributes the seed of single-cross hybrids to all associations growing double crosses in accordance with their previously announced requirements. Some private establishments, however, obtain their foundation seed stocks from abroad.

25. MINIMUM SEED CERTIFICATION STANDARDS

The International Crop Improvement Association is an organization of seed-certifying agencies in the United States and Canada. This association was organized in 1919. Its members are responsible for seed certification in most of the States of the United States and in all of Canada. The principal office of the association is at the address of the secretary. Information regarding the location of current officers can be secured at any time from member associations. The purpose of the association is to assist the member agencies in promoting the production, identification, and distribution of high quality seed of superior crop varieties which are approved by the state or provincial experiment stations.

The following minimum seed certification standards for maize, which are in all essentials identical with the Seed Certification Standards of the International Crop Improvement Association employed in Canada and the United States of America, were considered and approved, in both the English and French texts, by delegates of 13 governments in Europe and the Mediterranean region at the Sixth Meeting of the European Breeders of Hybrid Maize organized by FAO at Lisbon, Portugal, February 9-14, 1953.

With a view to facilitating international trade in high quality seed of maize, the meeting requested the Director-General of FAO to transmit these approved minimum standards to the governments in Europe and the Mediterranean region for adoption. The meeting emphasized that these are minimum standards that should be established and that more stringent requirements could be adopted wherever feasible.

The following standards are quoted from the original report (FAO, 1953c).

General Requirements

Type of certifying organization

Certification should be conducted by a state or provincial agency or a non-profit organization of seed growers recognized by the State and not financially dependent on persons or organizations having interests

in the production of and trade in maize seed. In either case the organization or agency should be designated under state or provincial legislation and have a close working relationship among seed growers and agricultural research, extension, and seed regulatory agencies.

Publication of standards and procedures

All standards and procedures of seed certification agencies must be available in published form.

Qualifications of inspectors

Inspection shall be performed only by personnel trained for this purpose.

Purpose of certification

The purpose shall be to maintain and make available to the public, through certification, high quality seed of hybrid maize or maize varieties so grown and distributed as to insure genetic identity and genetic purity.

Definitions

1. *Inbred line*: An inbred line must be a relatively true breeding strain of maize resulting from at least five successive generations of controlled self-fertilization with selection or its equivalent.

2. *Single cross*: The first generation resulting from the controlled crossing of two certified inbred lines.

3. *Three-way cross*: The first generation resulting from the controlled crossing of a certified single cross and a certified inbred line.

4. *Double cross*: The first generation resulting from the controlled crossing of two certified single crosses.

5. *Top cross*: The first generation resulting from the controlled crossing of a certified inbred line and a certified open-pollinated variety or, equally, the first generation resulting from the controlled crossing of a certified single cross and a certified open-pollinated variety.

6. *Varietal cross*: The first generation resulting from the controlled crossing of two certified open-pollinated varieties.

7. *Open-pollinated variety*: Only a variety which is relatively uniform and certified.

Eligibility requirements for certification

Only those hybrids and varieties that are approved by a state or provincial agricultural experiment station and accepted by the certifying agency shall be eligible for certification.

Establishing the source of seed

In those cases where the seed planted for the production of certified seed is obtained from another person, documentary evidence, such as a certification tag, sales record, etc., must be submitted to the certifying agency to establish source of seed.

Restrictions on the number of varieties

Only one hybrid or variety of maize may be grown for seed production on a farm except on prior approval of the certifying agency. It is advisable, in seed-producing districts, to arrange for voluntary or compulsory zoning of varieties or hybrids so as to facilitate isolation.

Handling of the crop prior to inspection

Roguing of off-type plants, objectionable crop plants, and weeds is required prior to field inspection.

Contaminating crops and varieties

Every field for which certification is requested shall show evidence of good management and shall show that reasonable precaution has been taken to control contaminating crops and varieties.

Seed treatments

It is desirable that all certified seed be treated with a suitable seed fungicide.

Samples and sampling of seed

Representative samples of each lot of seed as it is offered for sale shall be drawn by the certifying agency, which shall subsequently seal the lot. Sampling shall be in accordance with the rules of the International Seed Testing Association. Samples shall be retained for reference by the certifying agency for at least 12 months.

Seed house or bin inspection of seed

One or more inspections of harvested lots of seed from inspected fields may be made at any time by representatives of the certifying agency, who shall have authority to reject for certification any lot not properly protected from mixture or not properly identified.

Seed testing

Analyses and tests of samples of seed and definitions of analytic terms shall be in accordance with the rules of the International Seed Testing Association. Purity shall be determined by the "quicker method" as defined in those rules.

Tags and seals

All seed stocks when sold as certified seed shall have an official tag properly affixed to each container. Sealing requirements will depend upon the methods of handling. The certification tag which is attached to the bag serves as evidence of the genetic identity and genetic purity of the seed contained therein.

The following colored tags should be used to designate quality for the certified seed:

1. blue tag for first-quality seed;
2. red tag for second-quality seed.

A sealing device which cannot be removed and reattached is added protection to the final planter or consumer that the seed received is that originally certified. All official certification tags and seals must be affixed to seed containers by a representative of the certifying agency. A certification tag shall contain the following information only:

1. name and address of vendor;
2. name and address or code designation of producer;
3. name of certifying agency;
4. whether hybrid of open-pollinated variety;
5. designation of hybrid or variety;
6. whether first-quality or second-quality seed;
7. germination capacity and date of determination;
8. purity;
9. inert matter;
10. weed seed;
11. other varieties;
12. moisture content and date of determination;
13. grade (state whether large flats, medium flats, small flats, large rounds, or medium rounds);
14. fungicide (state kind used).

Certification tags used in international trade shall be in the English or French language. It is recommended that the certification tags be copyrighted in each country so as to make imitations unlawful.

Second-quality seed

It is recognized that certain lots of seed that may be desirable for the advancement of crop improvement would be lost if regular certification standards were adhered to. Therefore, under such circumstances, seed failing to meet certification standards other than those affecting genetic purity may be certified as second-quality seed, provided there is no injury to the reputation of certified seed. The certification tag attached to such seed shall show clearly the respects in which the seed does not meet the regular certification standards; it shall be of red color.

Responsibility

Responsibility for all obligations, including germination capacity, arising from the sale or shipment of seed which has been certified rests with the grower or subsequent handler making the sale or shipment.

Restrictions on usage of the word "hybrid"

To avoid confusion or misrepresentation, the word "hybrid" shall be used on labels, tags, invoices, advertising material, etc., only in connection with single crosses, three-way crosses, double crosses, top crosses, or varietal crosses.

Commercial Hybrids

Application and amplification of general certification standards

The general requirements are basic and, together with the following specific standards, constitute the standards for certification of commercial maize hybrids. The general requirements are amplified as follows to apply specifically to commercial maize hybrids:

Eligibility requirements for certification. A commercial hybrid may be any one of the following:

1. *A single cross*, i. e., the first-generation cross resulting from the controlled crossing of two certified inbred lines, to be used for grain or silage purposes and not for the production of double crosses or three-way crosses.
2. *A double cross*, i. e., the first generation resulting from the controlled crossing of two certified single crosses.
3. *A three-way cross*, i. e., the first generation resulting from the controlled crossing of a certified single cross and a certified inbred line.
4. *A top cross*, i. e., the first generation resulting from the controlled crossing of a certified inbred line and a certified open-pollinated variety, or the first generation resulting from the controlled crossing of a certified single cross and a certified open-pollinated variety.
5. *A varietal cross*, i. e., the first generation resulting from the controlled crossing of two certified open-pollinated varieties.

To be certified, a field maize hybrid for grain must not yield significantly lower than widely-used adapted hybrids or varieties when tested in their region of adaptation. It must be such that under normal conditions it will be sufficiently early in maturity to produce sound grain and be relatively resistant to lodging and have husk protection where necessary. To be certified, a field maize hybrid for green fodder or silage must be a hybrid recognized by the certifying agency for that purpose.

Classes and sources of certified seed. Only the class " Certified " is recognized. A commercial hybrid, to be certified, must be produced from certified foundation seed or seed stocks approved by the certifying agency and must represent a specific combination that has been compared by a state or provincial agricultural experiment station or certifying agency in adequately replicated experiments with widely used hybrids or varieties known to be adapted to the locality of the comparison.

Land requirements

There are no requirements as to the previous crop.

Field inspections

At least three field inspections shall be made by a certifying agency inspector during the pollinating period, these inspections to be made without previous notification to the grower.

Field standards

Unit of certification. The entire area of any one specific commercial hybrid grown by and/or belonging to one applicant and used for seed must be eligible and must be inspected.

Isolation. A specific commercial hybrid to be inspected for certification must be so located that the seed parent is not less than 200 meters from other maize, provided, however, that if the kernel color and/or type of the contaminating field are the same as those of the parents in the crossing field, the distance may be modified, depending on the acreage of the specific cross, by the planting of border rows of pollen parent as shown in Table 53.

This Table applies to all sides of the specific cross exposed to contamination from other maize, whether located directly opposite or diagonally, and indicates the minimum number of border rows required for acreages of various sizes when located at different distances from the contaminating maize. Differential maturity dates are permitted for modifying isolation distances, provided there are no receptive silks in the seed parent at the same time pollen is being shed in the contaminating field.

TABLE 53. — ISOLATION REQUIREMENTS FOR THE PRODUCTION OF COMMERCIAL HYBRID SEED

When the field area (in hectares) growing the affected seed parent is:								
4 or less	4–5.9	6–7.9	8–9.9	10–11.9	12–13.9	14–15.9	16 or over	Then at least this no. of border rows is required
And the distance (in meters) of the seed parent from other maize is at least:								
200.0	195.0	190.0	185.0	180.0	175.0	170.0	165.0	1
187.5	182.5	177.5	172.5	167.5	162.5	157.5	152.5	2
175.0	170.0	165.0	160.0	155.0	150.0	145.0	140.0	3
162.5	157.5	152.5	147.5	142.5	137.5	132.5	127.5	4
150.0	145.0	140.0	135.0	130.0	125.0	120.0	115.0	5
137.5	132.5	127.5	122.5	117.5	112.5	107.5	102.5	6
125.0	120.0	115.0	110.0	105.0	100.0	95.0	90.0	7
112.5	107.5	102.5	97.5	92.5	87.5	82.5	77.5	8
100.0	95.0	90.0	85.0	80.0	75.0	70.0	65.0	9
87.5	82.5	77.5	72.5	67.4	62.5	57.5	52.5	10
75.0	70.0	65.0	60.0	55.0	50.0	45.0	40.0	11
62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	12
50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0	13

Detasseling. The following requirements apply only when 5 percent or more of the parent plants have apparently receptive silks. A commercial hybrid will be disqualified for certification if more than 1 percent of the seed parent stalks have shed pollen on any one inspection or if the total for three inspections on different dates exceeds 2 percent. Sucker tassels, portions of tassels, or tassels on main plants will be counted as shedding pollen when 2 inches or more of the central stem, the side branches, or a combination of the two have the anthers extended from the glumes.

Purity requirements. A seed field in which more than 0.2 percent off-type or more than 2.0 percent doubtful-type plants in the pollen-parent have shed pollen will not be certified. At the time of the last inspection, the seed parent shall not contain in excess of 0.2 percent off-type or 2.0 percent doubtful-type plants.

Seed standards

Factors	*Standards for certified seed of first quality, percentage*
Pure seed (minimum)	98.0
Inert matter (maximum)	2.0
Weed seed	none
Other varieties (maximum)	0.2
Germination capacity	90.0
Moisture (maximum)	14.0

Foundation Single Crosses

Application and amplification of general certification standards

The general requirements are basic and, together with the following specific standards, constitute the standards for certification of foundation single crosses of maize. The general requirements are amplified as follows to apply specifically to foundation single crosses of maize:

Eligibility requirements for certification. A foundation single cross, to be eligible for certification, must be produced from inbred lines whose source assures their identity. Only the class "Certified" is recognized. A foundation single cross shall be the first generation resulting from the controlled crossing of two certified inbred lines for use in the production of double, three-way, or top crosses. In case of shortage of first-generation seed, second-generation seed of foundation single crosses shall be eligible for certification for use in the production of double, three-way, or top crosses, provided such seed has been produced under conditions approved by the certifying agency. Foundation single crosses shall be ear-inspected after maturity by the certifying agency.

Land requirements

There are no requirements as to the previous crop.

Field inspections

At least four inspections shall be made by an inspector of the certifying agency before and during the pollinating period, said inspections to be made without prior notice to the grower.

Field standards

Unit of certification. The entire area of any one specific foundation single cross grown by and belonging to one applicant must be eligible and be inspected. Any field or portion of a field failing to meet requirements must be so disposed of that it cannot be used for seed purposes.

Isolation. A specific foundation single-cross field shall be so located that the seed parent is not less than 200 meters from other maize except that differential maturity dates may permit modifying this distance, provided that there are no receptive silks in the seed parent at the time pollen is being shed in the contaminating field.

Detasseling. The following requirements apply only when 5.0 percent or more of the seed parent plants have apparently receptive silks. A foundation single cross will not be accepted for certification if on any inspection more than 1.0 percent of the seed-parent plants have shed pollen on any one inspection or if the total for three inspections on different dates exceeds 2.0 percent. When more than one combination is being grown in the same isolation area and the seed parent of one or more of them is shedding pollen in excess of 1.0 percent, all seed parents having 5.0 percent or more apparently receptive silks at that time will be disqualified unless adequately isolated from the shedding seed parent.

Sucker tassels, portions of tassels, or tassels on main plants will be counted as shedding pollen when 2 inches or more of the central stem, the side branches, or a combination of the two have the anthers extended from the glumes.

Purity requirements. A foundation single-cross seed field in which more than 0.1 percent off-type or more than 2.0 percent doubtful-type plants in the pollen parent have shed pollen will not be certified. At the time of the last inspection, the seed parent shall not contain in excess of 0.1 percent off-type or 2.0 percent doubtful-type plants.

Seed standards

Foundation single crosses shall not contain in excess of 0.1 percent of off-type ears or more than 0.2 percent of ears with kernels off type in color, size, texture, or other features.

Inbred Lines

Application and amplification of general certification standards

The general requirements are basic and, together with the following specific standards, constitute the standards for certification of inbred lines of maize. The general requirements are amplified as follows to apply specifically to inbred lines of maize.

Eligibility requirements for certification. An inbred line, to be eligible for certification, must be from a source such that its identity may be assured. An inbred line must be a relatively true breeding strain of maize resulting from at least five successive generations of controlled self-fertilization with selection or its equivalent. Only the class "Certified" is recognized. Inbred lines shall be ear-inspected after maturity by the certifying agency.

Land requirements

There are no requirements as to the previous crop.

Field inspections

At least four inspections must be made by an inspector of the certifying agency before and during the pollinating period, these inspections to be made without prior notice to the grower.

Field standards

Unit of certification. The entire area of any one inbred line grown by and belonging to one applicant must be eligible and be inspected. Any field or portion of a field failing to meet requirements must be so disposed of that it cannot be used for seed purposes.

Isolation. An increase field of an inbred line must be so located that it is not less than 200 meters from any other kind of maize except that differential maturity dates may permit modifying this distance, provided that there are no receptive silks in the inbred line at the time pollen is being shed in the contaminating field.

Purity requirements. A field which contains, at any one inspection, more than 0.1 percent of off-type or more than 2.0 percent of doubtful-type plants that have shed or are shedding pollen when 5.0 percent or more of the plants in the field have receptive silks, shall not be certified. Sucker tassels, portions of tassels, or tassels on main plants will be counted as shedding pollen when 2 inches or more of the exposed central stem, the side branches, or a combination of the two have the anthers extended from the glumes.

Seed standards

Inbred lines shall not contain in excess of 0.1 percent of off-type ears, or more than 0.2 percent of ears with kernels off type in color, size, texture, or other features.

26. POLICIES AND LEGISLATION

Most states and countries have developed policies and legislation concerning the production, sale, and distribution of hybrid maize seed. Definite, uniform policies among co-operating agencies promote the free interchange of breeding materials, performance test data, and improved techniques. Uniform policies also eliminate confusion that may develop if each agency has a different policy. Most states and countries have regulations defining inbred lines and the various types of hybrids. Typical definitions are included in Chapter 25.

Release and Use of Inbred Lines

Three general policies on the release and distribution of inbred lines of maize include immediate release, nonrelease, and delayed release.

Immediate release permits the distribution of an inbred line from the originating agency to anyone without any restrictions at any time during the development process. Few states or countries have utilized the immediate release policy.

The non release policy implies that an inbred line will never be released to the public by the originating agency. This policy has been used in some areas of the United States. In such cases, these workers do not release their inbred lines to commercial maize breeders or workers. Usually, however, the inbreds are available to co-workers in other state agricultural experiment stations. Workers in these other states, however, usually agree not to release the lines to commercial agencies. Under this policy, the experiment station maintains the inbred lines used in its program, and also produces seed of the foundation single crosses required in the production of recommended double-cross hybrids. In some states, this work is done by foundation seed organizations or commercial seed companies under contract with the experiment station. Most workers agree that it is practically impossible to prevent the ultimate release of inbred lines.

Delayed-release policy prescribes the control of a new inbred line by the originating agency during the early years of its semicommercial

TABLE 54. — INBRED LINES RELEASED TO PRIVATE GROWERS FROM STATE AND FEDERAL AGENCIES IN THE UNITED STATES

Colorado	Connecticut	Florida	Georgia	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Michigan	Minnesota	
M49	C102	F6	GT112	A	Tr	PR	K41(W)	Ky21(W)	L578	MS24	C-11	A305(W)
R19-8	C103	F44		K	Pr-1	B6	K55(W)	Ky27(W)	L2-2(W)	MS206	A21	A308(W)
	C105			L	B2	B7	K63(W)	Ky30A(W)	L10(W)		A25	A310(W)
	C106			Hy	H5	B8	K64(W)	Ky39(W)	L44(W)		A34(W)	A312(W)
	C107			Hy2	K6(W)	B9	K148	Ky49(W)	L62(W)		A71	A334
				R2	P8	B10	K150	Ky56(W)	L90(W)		A73	A340
				R4	WF9	B14	K155	Ky58(W)	L91 (W)		91(W) Imp.	A344
				M14	H21(W)	B16	K166	Ky122(W)			A96	A357
				R30(W)	H22(W)	B21	K201				A111	A374
				R53	H23(W)	4Co31(W)					A116	A375
				R59	H25(W)	4Co63(W)					A148	A385
				R61	33-16(W)	4Co82(W)					A166(W)	A392
				R71	38-11	4Co101(W)					A171(W)	A395
				R109B	K44(W)	Ia.153					A188(W)	A401
				R113	K61(W)	I.159					A203	A417
				R168		I.197					A208	A427
				4266		I.205					A218	A495
				5120		I.224					A223	A498
				5120B		I.234					A257	A502
				90		L289					A286	A509
						L317					A293	A513
						B1.345					A295	A556
						B1.349						
						KB397						
						Mc401						
						OS420						
						OS426						
						CI.447						
						WD456						
						ITE701						

TABLE 54 — INBRED LINES RELEASED TO PRIVATE GROWERS FROM STATE AND FEDERAL AGENCIES IN THE UNITED STATES *(concluded)*

Missouri	Nebraska	New York	N. Carolina	N. Dakota	Ohio	Pennsylvania	S. Dakota	Texas	U.S.D.A.	Wisconsin
G	N1	NY2	NC7	WD	Oh02	Pall	SD105	Tx4R-3W	Cl.1	WD
Mol(W)	N6	NY3	NC13	ND1	Oh05	Pa32		Tx61M(W)	Cl.2	WH
B2	N15	NY H1	NC33(W)	ND5	Oh07	Pa34		Tx102A(W)	Cl.3	WJ
L3	N16	NY16	NC34(W)	W9	Oh7A	Pa70		Tx155A(W)	Cl.3A	WR3
Mo3	N72(W)			WM13	Oh07B	Pa86		Tx127C	Cl.4-8	W8
K4				ND30	Oh26			Tx132A	Cl.5	W9
Mo21R				ND36	Oh26A			Tx173D	Cl.7	WM13R
Mo22				W49	Oh28			Yx203	Cl.11B(W)	W22
B41				A90	Oh33			Tx303	Cl.21	W23
				A111	Oh40B			Tx325	Cl.21E	W25
				W153	Oh41				Cl.23(W)	W32
				ND203	Oh43				Cl.24(W)	W37A
				ND230	Oh45				Cl.27	W49
				ND255	Oh51				Cl.28A	W64A
				ND283	Oh51A				Cl.31	W153R
					Oh56				Cl.38B	W182
					Oh56A				Cl.41(W)	W182B
					Oh65				Cl.42A	W187R
					Oh84				Cl.43(W)	
									Cl.61(W)	
									Cl.61(W)	
									Cl.64(W)	
									Cl.187-2	
									Cl.317B	
									Cl.540	

SOURCE: Henderson, 1956.

utilization, but before its full release to the public. Usually, the multiplication of a new inbred line and the production of single crosses from it are handled by the station or by some agency designated by the station and under its control for a period of from two to five years after hybrids involving the inbred line have been approved by the station for commercial production. The inbred line is released to the public after this probationary period. Inbreds once released may be distributed by any station; unreleased lines, however, may be distributed by other stations only with the consent of the originating station.

The policy of delayed release requires that each station must have means of growing, processing, storing, and distributing limited amounts of foundation seed under careful supervision and close control. Provision of such facilities enables these stations to utilize, without distributing them, inbred lines from stations which prefer not to release their inbred lines. This policy facilitates the use of exchanged lines by all stations.

The delayed-release policy has been used for many years by workers in the northern half of the United States. Tentative plans are being made to change to the delayed-release policy in the southern part of the United States. Henderson (1956) prepared a list of inbred lines released to private growers from state and federal agencies in the United States (Table 54).

Jenkins, in the Report of the Seventh FAO Hybrid Maize Meeting in 1954, pointed out that the decision on releasing inbred lines of maize in any European or Mediterranean country should be influenced by plans for the production of foundation seed in that country. If double-crossed seed is to be produced by commercial seedsmen, it is desirable to release the inbred lines to them. If seed production is to be under the complete control of the state or country, there may be less need for releasing the inbred lines to private growers.

Workers at the Seventh FAO Hybrid Maize Meeting recommended that inbred lines developed in European and Mediterranean countries be released to private seed producers, under necessary safeguards, without delay after their value in hybrid combinations had been proved in cooperative tests.

Designation of Inbred Lines and Hybrids

Most inbred lines and hybrids are designated by number rather than by name. Such a system results in duplication of numbers among States and countries. In an effort to eliminate confusion, corn breeders usually assign prefixes before the number of the inbred and hybrid.

The Northern Regional Committee, at the Sixth FAO Hybrid Maize Meeting in 1953, discussed the designation of inbred lines. This committee

recommended that inbred lines be designated by not more than two letters giving the country of origin, followed by a number of not more than two digits. The letters designating the country of origin shall be those used in automobile registration. The following designations were chosen for the ten European countries represented in the committee:

EP	Spain - Pontevedra
FC	France - Clermont-Ferrand
FV	France - Versailles
BM	Belgium - Melle
GB	Great Britain - Oxford/Cambridge
NL	Netherlands - Wageningen
DS	Germany - Scharnhorst
CH	Switzerland - Zürich/Lausanne
S	Sweden
DK	Denmark
Au	Austria

Prefixes for the designation of inbred lines in the United States and Canada are listed in Table 55.

TABLE 55. — LIST OF PREFIXES FOR INBRED LINES IN THE UNITED STATES AND CANADA

State	Prefix	State	Prefix
Alabama	Ab	Michigan	MS
Arizona	Ar	Minnesota	A
Arkansas	Ak	Mississippi	Mp
Canada, Harrow	CH	Missouri	Mo
,, Morden	CM	Montana	Mt
,, Ottawa	CO	Nebraska	N
,, Quebec	Q	New Jersey	J
Colorado	Co	New York	NY
Connecticut	C	North Carolina	NC
Florida	F	North Dakota	ND
Georgia	G	Ohio	Oh
Idaho	Id	Oklahoma	Ok
Illinois	R	Pennsylvania	Pa
Indiana	H	South Carolina	SC
Iowa	B	South Dakota	SD
Kansas	K	Tennessee	T
Kentucky	Ky	Texas	Tx
Louisiana	L	U.S. Dept. Agr.	Cl.
Maryland	Md	Virginia	Va
Massachusetts	Ma	West Virginia	WV
		Wisconsin	W

Co-operative maize improvement programs often result in cases where a specific hybrid receives different designations. In an effort to remedy this situation, procedures have been developed for assigning uniform designations to hybrids that have performed well over a wide

area of testing. The uniform designation may consist of a regional name followed by a number which indicates maturity.

The regional prefix in the Corn Belt of the United States consists of the letters "AES" for agricultural experiment stations. The northeastern maize workers of the United States have adopted " Eastland " as their regional name. These areas have similar systems of numbers to indicate relative maturity. Hybrids are classified by reference to standard hybrids. The nine maturity classes and type hybrids recommended for use as maturity standards are shown in Table 11 on page 118.

The workers in the southern part of the United States have adopted " Dixie " as their prefix for hybrids with regional adaptation. The accompanying number in their system designates between yellow and white hybrids. Yellow hybrids are assigned even numbers, and white hybrids are assigned odd numbers.

Delegates attending the Seventh FAO Hybrid Maize Meeting in 1954 agreed on a uniform policy for designating hybrids developed in the European and Mediterranean regions. They agreed that the name for the hybrids developed in each country should be a prefix designation of not more than three syllables, indicative, if possible, of the country of origin and also easy to understand and use. The name should be followed by a three-digit number in which the first digit indicates the relative maturity. The second digit should give some indication of the relative maturity within each group. In the third digit, even numbers indicate yellow hybrids and odd numbers white hybrids. Precautions should be taken to prevent the same hybrid, if developed in different contries, from receiving more than one name. A competent regional committee could act as a clearing house.

The desirability of introducing an international seal for hybrids recognized as being suitable for several countries needs consideration. The nine maturity classes and type hybrids recommended for use as maturity standards in Europe and Mediterranean countries are shown in Table 11 on page 118.

Closed Versus Open Pedigrees

Hybrids may be developed by workers in government agencies or in commercial companies. The pedigrees of hybrids developed by government agencies are usually published. The pedigrees of hybrids developed by commercial agencies, however, are usually trade secrets in most countries. Some states and countries do not permit synonyms or other names to be assigned to previously named hybrids. Such procedure, however, is very difficult to prevent.

Production, Sale, and Distribution of Seed

Relatively few regulations have been imposed on the hybrid seed industry in the United States. Some states require a license for the sale of hybrids recommended for use within the state. A few states have required that hybrid seed be certified before it is offered for sale. Most states and countries require that hybrid seed be the first generation of a cross involving inbred lines of maize.

Appendix

TABLES (I-VI)

TABLE I. — SUMMARY OF AGRONOMIC DATA ON 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948

Inbred line	Days to			Height of		Lodged plants		Plot yield, lbs.	Ears per plant, no.	Reaction to 2,4-D, grade [1]	Leaf firing, % [1]	Cold resistance, grade [1]	Mg. deficiency, grade [1]
	Half		Maturity	Plant, ins.	Ear, ins.	Root, %	Stalk, %						
	Pollen	Silk											
ND1	59	60	99	42	10	21	25	5.0	1.78	2		G	2.5
ND5	59	60	99	44	10	46	3	6.2	1.03	4		G	3.5
ND30	62	67	104	49	18	28	1	5.2	1.46	5		G	3.0
ND36	59	60	97	44	11	58	66	8.1	1.92	4		F	3.5
ND167	64	66	103	45	12	23	3	4.9	1.31	4		P	2.5
ND203	67	70	104	44	15	23	0	5.6	1.77	4		VP	3.0
ND211	69	71	106	49	15	21	2	4.5	1.03	5		VP	3.5
ND230	65	67	108	62	18	46	4	10.9	1.04	5		G	3.0
ND255	63	66	104	47	14	40	4	5.8	0.98	4		VP	2.0
ND283	68	70	105	48	16	32	15	4.7	1.23	4		VP	3.0
SD102	70	71	113	61	17	44	2	8.7	0.96	5		F	4.0
SD104	65	68	109	50	15	7	0	7.1	1.00	3		F	3.0
SD105	66	71	112	49	16	22	0	7.5	1.31	3		VP	2.0
SD106	68	72	113	45	16	35	3	5.9	1.05	4		F	3.0
SD107	74	76	118	57	22	22	8	10.5	1.28	2		F	3.0
C.11	68	69	116	56	16	47	0	9.8	0.97	5		F	2.5
C.11 Imp.	68	69	117	57	17	34	2	12.1	1.00	4		F	3.0
C.14	69	70	112	54	21	33	0	5.3	1.27	5		P	3.0
C.14 Imp.	68	70	113	56	21	21	3	6.9	1.23	4		F	2.5
A7	70	71	110	62	21	56	1	9.1	0.94	5		G	4.0
A12	68	70	105	54	18	24	1	5.0	0.91	2		G	4.5
A15	59	67	108	54	17	57	14	7.1	1.12	5		G	4.0
A21	65	67	108	48	17	16	1	4.1	1.00	2		F	5.5
A25	80	81	131	71	26	6	0	9.6	1.00	4		F	3.5
A34	68	69	113	58	18	88	2	7.9	1.00	4		F	4.0
A71	76	78	126	68	27	4	2	11.0	1.22	5		F	3.0
A73	79	81	126	54	21	0	0	11.1	1.06	3		F	3.0
A90	70	72	112	48	16	27	2	8.9	1.00	3		VP	3.0
A96	70	71	111	58	19	58	18	9.0	.96	4		F	1.5
A111	67	70	107	52	15	13	1	5.2	1.00	2		G	3.0

For notes, see end of Table I, page 321.

TABLE I. — SUMMARY OF AGRONOMIC DATA ON 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1943 (*continued*)

Inbred line	Days to			Height of		Lodged plants		Plot yield, lbs.	Ears per plant, no.	Reaction to 2,4-D, grade [1]	Leaf firing, % [1]	Cold resistance, grade [1]	Mg. deficiency, grade [1]
	Half		Maturity	Plant, ins.	Ear, ins.	Root, %	Stalk, %						
	Pollen	Silk											
A116	71	64	116	59	23	29	2	6.3	1.17	3		F	4.0
A131	71	74	112	56	16	13	16	7.1	0.93	5		VP	2.0
A148	67	68	116	58	22	45	1	8.3	1.03	4		VG	3.0
A158	68	71	115	56	19	33	4	10.4	1.01	2		G	.5
A165	67	69	112	57	21	46	8	4.8	1.03	2		G	1.0
A166	71	73	117	62	25	2	13	10.2	1.12	4		VG	2.5
A171	66	69	110	62	19	40	2	8.8	1.22	3		VG	3.0
A188	71	72	119	55	17	4	1	9.3	1.20	3		G	2.0
A311	79	81	123	73	31	26	8	9.6	1.02	4		F	2.0
A322	76	78	124	65	28	4	5	9.7	1.10	4		G	2.5
A334	73	75	117	56	21	2	3	5.8	0.98	2		F	4.0
A340	72	74	118	64	23	1	0	8.5	1.03	3		G	3.0
A344	68	69	113	52	17	33	9	9.5	1.26	2		G	2.0
A347	76	78	119	56	22	4	14	10.3	1.08	4		VP	2.5
A357	74	74	115	62	24	4	19	9.6	1.01	5		VP	2.5
A374	74	75	118	68	28	6	0	14.1	1.30	5		G	3.5
A375	74	75	123	62	23	2	3	10.9	1.09	5		G	2.5
A385	71	71	114	54	23	1	13	9.4	1.17	4		G	4.0
A392	73	76	118	63	28	4	10	8.7	1.00	3		F	4.0
A395	80	83	125	80	34	6	1	12.2	1.58	4		G	2.5
WR3	73	77	120	73	30	8	7	13.3	1.05	4		F	2.5
W8	75	75	124	61	25	1	7	9.3	1.25	4	60	G	1.0
W9	68	69	115	63	24	32	5	12.8	1.00	4		VP	2.5
W16	71	73	116	59	19	22	1	11.6	1.02	3		F	4.0
W17	77	80	128	64	28	4	14	9.2	1.28	4	10	G	3.0
W20	80	81	131	71	30	2	2	10.9	1.22	4	50	VG	2.1
W22	77	79	126	60	22	4	2	8.5	1.56	4	60	VG	3.5
W23	78	81	121	77	30	3	4	10.2	1.26	4		G	1.5
W25	71	74	120	59	24	15	0	7.2	1.07	3		G	4.0
W26	77	80	123	62	26	18	1	8.7	0.95	3		G	3.5
W10	79	81	126	67	27	1	15	10.1	1.29	4		VG	2.0
MS206	66	65	109	60	21	65	4	6.4	0.98	4		G	2.0

TABLE I. — SUMMARY OF AGRONOMIC DATA ON 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948 (*continued*)

Inbred line	Days to			Height of		Lodged plants		Plot yield, lbs.	Ears per plant, no.	Reaction to 2,4-D, grade [1]	Leaf firing, % [1]	Cold resistance, grade [1]	Mg. deficiency, grade [1]
	Half		Maturity	Plant, ins.	Ear, ins.	Root, %	Stalk, %						
	Pollen	Silk											
N6	78	79	123	60	24	14	12	8.7	1.12	4	40	VG	3.5
Ia153	70	72	114	54	19	25	14	9.2	1.00	5		G	2.0
I.159	82	83	129	74	39	29	30	6.2	1.07	5	20		3.0
I.205	77	77	124	63	28	5	0	7.2	0.95	5	10	VP	2.0
I.224	77	78	124	75	32	6	3	9.2	1.37	4	30	VP	3.0
I.234	79	81	127	77	36	10	2	9.8	1.19	4	40	VP	2.1
L289	77	80	123	80	37	22	19	9.2	1.23	5	100	G	2.0
Os420	73	77	126	72	25	16	8	10.6	1.12	3	90	P	3.0
Os426	77	78	121	73	34	56	12	10.7	1.46	5	50	VG	2.5
L317	81	86	126	81	43	6	18	10.3	1.68	4	30	VG	3.1
B8	71	72	119	67	30	0	2	9.7	1.05	4		G	2.5
A	76	79	122	69	25	7	28	8.3	1.36	4	100	VG	3.0
L	75	78	128	58	26	23	3	12.1	1.22	4	60	G	2.0
90	80	81	127	57	25	6	5	7.7	1.23	4	30	VG	2.1
R4	78	81	124	74	28	11	11	8.8	1.50	4	60	G	1.1
Hy	78	80	130	74	36	3	13	9.6	1.07	3	40	G	3.0
Hy2	77	79	129	68	31	1	5	10.3	1.12	2	70	VG	3.1
512OB	83	86	132	75	33	0	12	10.5	0.98	3	40	F	2.0
M14	79	81	124	60	21	14	2	12.0	1.11	3		VG	4.0
4226	77	80	122	72	30	11	3	12.0	1.34	3		G	2.0
R2	79	80	121	67	25	3	4	9.5	1.31	2	50	G	2.0
R30	79	83	135	68	27	3	3	8.8	1.06	4	30	VG	2.1
R59	81	83	129	62	27	12	23	10.0	1.02	4	60	VG	5.0
R61	79	83	128	67	31	6	7	7.9	1.23	3	30	VG	1.0
66	78	82	129	66	23	8	1	8.0	1.21	4	30	F	2.0
Tr	78	80	130	64	27	23	0	11.4	1.15	4	30	G	1.0
B164	75	78	126	95	36	15	1	12.5	1.58	4	30	G	2.0
B2	75	78	128	67	30	14	5	7.0	0.95	3	60		2.1
WF9	77	79	128	66	25	32	1	9.8	0.93	4	30	VP	3.0

TABLE I. — SUMMARY OF AGRONOMIC DATA ON 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948 (*continued*)

Inbred line	Days to			Height of		Lodged plants		Plot yield, lbs.	Ears per plant, no.	Reaction to 2,4-D, grade [1]	Leaf firing, % [1]	Cold resistance, grade [1]	Mg. deficiency, grade [1]
	Half		Maturity	Plant, ins.	Ear, ins.	Root, %	Stalk, %						
	Pollen	Silk											
38-11	81	83	129	75	41	0	23	9.1	1.05	3	40		3.1
P8	80	83	135	72	32	3	5	10.7	1.31	4	100	VG	2.1
H5	76	79	120	72	30	2	9	6.0	1.15	5	80	G	3.5
Pr-1	80	80	123	66	40	12	5	9.0	1.04	4	20		2.1
33-16	77	79	127	74	37	4	8	10.6	1.03	5	0		1.1
H21	81	85	133	62	34	22	2	5.1	0.89	4	30		2.0
H22	78	80	131	72	40	27	35	6.4	1.16	4	40		3.0
H23	81	83	138	64	26	17	2	6.1	1.01	4	5		2.0
Oh02	77	79	120	67	31	41	12	7.6	1.34	4	100	G	3.0
Oh07	82	85	133	77	33	22	5	8.4	1.56	4	10	VP	3.1
Oh26	75	77	119	63	22	23	2	7.8	1.24	3		F	3.0
Oh28	79	80	125	64	25	17	3	10.3	1.57	4	40	G	1.5
Oh33	78	79	123	76	34	12	2	7.1	1.04	4	40	F	2.0
Oh40B	76	80	123	64	21	17	11	6.8	1.32	4	80	VG	3.0
Oh51	77	78	123	67	26	30	3	14.2	1.56	3		G	2.5
Oh51A	75	77	122	62	21	33	0	10.9	1.46	4		F	2.5
Oh65	80	79	122	48	17	7	7	3.9	1.58	3	40	VP	2.5
Oh84	76	78	120	48	14	6	7	5.4	1.45	4	100	VP	3.0
Kys	87	90	143	70	38	3	12	7.6	1.21	3	10		3.0
K4	86	89	148	68	35	11	32	8.3	1.68	3	20		1.1
K6	79	82	140	77	41	25	6	9.6	1.12	5	0		3.1
K41	78	80	126	61	29	2	8	6.1	1.01	4	30		4.1
K44	80	81	132	69	34	10	16	9.6	0.99	3	5		1.1
K55	79	82	136	63	27	30	4	8.9	1.17	4	5		4.0
K63	84	85	139	68	40	2	4	8.8	1.16	3	80		1.0
K64	87	87	140	74	37	3	0	10.3	1.15	4	20		3.0
K148	75	82	124	67	26	11	5	7.8	0.94	5	60		3.1
K150	77	80	133	71	35	5	5	8.0	1.16	4	20		2.0
K155	83	86	135	76	40	7	7	7.4	1.05	3	0		2.0

TABLE I. — SUMMARY OF AGRONOMIC DATA ON 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948 (*concluded*)

Inbred line	Days to			Height of		Lodged plants		Plot yield, lbs.	Ears per plant, no.	Reaction to 2,4-D, grade [1]	Leaf firing, % [1]	Cold resistance, grade [1]	Mg. deficiency, grade [1]
	Half		Maturity	Plant, ins.	Ear, ins.	Root, %	Stalk, %						
	Pollen	Silk											
K201	87	91	146	68	35	1	1	6.2	0.79	2	0		4.0
Mo.G	79	84	127	70	37	16	29	9.1	1.05	3	40		3.0
Mo.L3	81	85	128	77	43	29	12	6.0	1.27	4	30		3.0
Mo.2Rf	79	81	127	80	41	12	10	11.8	1.37	5	20		1.0
Mo.22	93	97	148	68	40	0	0	4.5	0.96	4	5		2.5
Ky21	85	87	142	72	40	2	44	9.2	0.96	3	20		2.0
Ky27	78	81	125	69	33	5	46	8.1	1.56	3	60		1.1
Ky39	84	86	143	86	49	10	18	8.5	0.96	5	5		4.0
Ky49	82	84	132	82	39	0	10	7.3	0.98	4	50		2.0
Ky58	84	85	136	65	32	21	37	7.6	1.52	5	80		5.0
Ky122	83	86	134	75	41	10	14	6.5	1.08	4	50		2.0
T18	83	85	143	77	42	8	9	9.0	1.40	4	5		2.0
4-8	78	83	124	70	24	6	3	3.8	0.97	4	90		5.0
540	80	83	124	77	41	5	3	6.8	1.53	4	50		2.0
187-2	75	79	123	65	33	3	7	6.6	1.48	5	100		2.1
Cl.2	86	90	134	77	34	2	1	6.2	1.23	3	30		4.0
Cl.3	86	90	134	66	36	6	23	7.9	0.93	4	10		1.3
Cl.3A	82	85	129	75	38	52	26	7.3	0.96	4	20		1.5
Cl.5	80	84	133	80	42	29	8	7.6	1.08	5	20		1.5
Cl.7	82	84	136	78	41	3	8	9.3	0.99	4	10		1.1
Cl.11b	89	69	135	68	32	1	15	5.6	0.80	3	30		2.5
Cl.23	87	93	139	81	41	1	3	2.1	0.65	4	20		3.5
Cl.41	84	87	135	77	45	2	6	7.8	1.52	4	40		3.0
Cl.43	83	88	130	76	36	53	5	5.1	0.91	4	50		4.0
Cl.61	87	91	137	69	25	6	4	4.6	1.25	3	100		3.0

[1] The smallest grade or percentage is the most resistant.

SOURCE: Compiled from Brunson Ullstrup and Dicke (1948).

TABLE II. — SUMMARY OF AGRONOMIC DATA ON 89 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1949

Inbred line	Days to			Moisture at harvest, %	Lodged plants		Height of		Plot yield, lbs.	Dropped ears, %	Cold test, stand, %
	Half		Maturity		Root, %	Stalk, %	Plant, ins.	Ear, ins.			
	Pollen	Silk									
*ND36	55	56	98	—	42	64	43	10	2.2	7	77
*ND230	61	63	104	—	28	49	63	18	5.2	3	92
*SD105	62	66	110	—	4	20	57	18	3.8	7	87
*SD107	68	69	112	—	12	42	61	23	6.0	4	72
*A25	70	74	121	—	15	12	75	22	6.3	0	96
*A71	70	73	122	—	13	28	76	29	5.8	8	93
*A73	70	73	123	—	3	22	57	20	5.8	11	92
*A96	65	65	109	—	30	42	60	18	4.9	0	100
*WR3	67	70	112	—	12	32	71	25	5.4	4	88
*W22	72	75	127	—	8	5	61	20	5.7	7	87
W32	71	73	122	—	3	50	64	27	7.2	0	94
W38	72	75	127	—	6	23	76	29	6.6	21	94
W62	73	75	128	—	14	7	70	23	7.6	0	76
W70	71	74	123	—	6	14	71	26	5.5	0	92
W74	73	77	124	—	3	21	74	25	5.3	0	93
W136	73	75	123	—	11	7	71	23	6.0	3	92
W146	70	74	121	—	11	20	72	23	6.6	3	83
W164	71	73	120	—	6	8	69	25	4.7	4	84
MS1	75	80	130	—	25	19	82	37	4.2	0	79
MS19	67	68	115	—	28	10	73	30	3.8	7	72
MS24	67	69	114	—	12	27	54	22	5.9	0	91
Mean	69	71	118	—	14	25	67	23	5.5	4	87
N1	72	73	128	14.6	13	9	77	25	8.1	7	93
N2	72	74	128	16.4	3	34	76	28	6.5	14	86
*Ia 153	63	65	110	13.2	18	58	60	21	4.9	13	87
*I.205	72	73	122	17.3	9	9	68	28	5.6	5	81
L304A	73	74	128	16.0	13	22	76	33	6.2	7	85
*L317	78	83	127	19.5	9	29	83	41	4.4	3	74
*Os420	70	73	122	15.2	14	19	75	26	6.0	7	86
B6	75	77	126	23.0	8	8	68	26	8.1	17	68

For notes, see end of Table II, page 324.

TABLE II. — SUMMARY OF AGRONOMIC DATA ON 89 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1949 (*continued*)

Inbred line	Days to			Moisture at harvest, %	Lodged plants		Height of		Plot yield, lbs.	Dropped ears, %	Cold test, stand, %
	Half		Maturity		Root, %	Stalk, %	Plant, ins.	Ear, ins.			
	Pollen	Silk									
B7	74	78	129	17.3	2	6	76	27	5.3	3	86
*B8	68	68	119	13.3	8	23	66	29	4.5	4	92
B14	73	76	130	14.2	7	1	75	28	5.6	3	88
B32	75	78	129	17.2	9	30	77	30	6.6	20	82
*M14	72	73	124	14.8	6	7	61	19	6.8	0	90
*A	71	75	124	14.5	7	30	64	20	5.4	0	95
*Hy2	72	75	129	15.1	6	16	68	30	7.3	0	95
*R30	71	73	129	17.8	9	14	59	19	5.6	0	83
L5	75	79	130	16.3	5	10	74	29	4.8	3	63
L13	74	76	128	15.5	3	6	74	29	5.6	7	95
L17	73	75	128	16.8	7	5	69	28	8.7	13	90
L18	74	75	129	16.5	5	4	72	25	5.7	3	81
L29	76	77	132	17.4	4	11	74	31	9.0	7	78
L30	75	77	130	14.2	0	32	76	35	8.5	0	71
L34	73	77	129	16.6	1	11	69	29	6.3	0	81
L39	70	72	127	15.7	2	26	72	28	6.6	14	87
54-14	68	70	125	15.2	8	25	58	19	4.0	0	98
*WF9	72	73	129	17.3	11	4	71	26	8.4	0	90
*Tr	73	74	130	18.6	14	10	65	25	7.1	0	68
T92	75	79	134	15.3	8	22	73	32	5.6	3	92
T96	77	80	133	14.7	5	14	80	36	6.2	7	69
*38-11	78	81	135	15.2	4	10	77	35	6.6	3	52
*P8	75	78	132	15.7	14	10	74	28	9.1	0	90
*33-16	76	79	128	17.1	5	13	81	33	9.3	20	77
*H21	78	81	134	14.5	10	5	71	29	1.9	0	—
H25	80	82	136	14.9	23	2	87	33	6.5	0	58
*Oh07	78	81	137	17.0	11	2	82	29	5.4	0	80
Oh7B	79	84	138	14.9	5	10	87	34	5.5	0	58
*Oh26	68	69	121	13.1	17	10	67	22	4.0	3	87
*Oh28	72	74	125	14.9	17	11	65	23	8.3	3	91
Oh29	78	79	131	19.4	7	4	82	31	10.1	0	81
*Oh40B	70	74	126	14.3	18	11	72	23	6.1	3	92
Oh41	77	79	132	15.2	7	23	72	31	8.8	7	78
Oh43	69	71	125	14.5	0	2	64	19	7.1	7	95
*Oh45		71	126	18.9	7	3	70	20	9.1	0	87
*Oh51A	68	70	125	14.5	19	11	68	22	6.4	0	84
Oh56A	68	70	121	13.6	5	16	62	22	6.4	3	76

TABLE II. — SUMMARY OF AGRONOMIC DATA ON 89 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1949 (*concluded*)

Inbred line	Days to			Moisture at harvest, %	Lodged plants		Height of		Plot yield, lbs.	Dropped ears, %	Cold test, stand, %
	Half		Maturity		Root, %	Stalk, %	Plant, ins.	Ear, ins.			
	Pollen	Silk									
C103	74	78	132	16.2	14	3	80	27	5.3	4	83
Mean	73	75	128	15.9	9	14	72	27	6.5	5	82
*Kys	79	81	137	20.7	4	11	75	37	5.2	0	—
*K4	79	82	145	22.7	19	10	69	30	4.7	0	—
*K41	69	70	108	18.0	38	5	62	21	3.6	0	—
*K44	74	75	134	16.4	10	28	72	28	6.7	3	—
K61	71	74	133	15.5	39	21	87	39	7.8	0	—
*K64	78	79	138	17.9	11	1	77	31	6.5	3	—
*K201	77	78	142	18.7	5	10	73	34	4.2	0	—
Mo.557	71	74	108	22.8	13	38	69	26	5.7	20	—
Mo.567	70	71	108	17.7	24	7	89	37	9.7	7	—
Mo.572	77	79	144	18.2	9	4	89	36	4.7	14	—
Mo.577	72	74	121	18.6	13	27	69	24	6.5	14	—
Mo.580	72	75	129	18.0	16	58	58	30	6.7	3	—
*Ky27	73	76	126	16.1	13	55	72	30	5.8	3	—
*Ky122	75	78	131	17.0	4	15	80	37	5.3	7	—
Ky36-11	75	78	140	20.1	14	9	70	29	8.7	0	—
T8	78	80	129	19.4	16	5	82	40	6.0	10	—
*Cl.7	76	77	127	19.8	1	2	86	37	7.0	10	—
*Cl.187-2	70	75	129	14.7	9	7	70	30	5.1	0	—
Cl.21	80	82	145	24.3	15	1	93	41	6.4	0	—
Cl.21E	75	78	131	16.4	4	5	79	31	8.3	0	—
Cl.27	73	77	135	18.2	14	3	81	31	5.0	0	—
K64 (rec.)	75	76	127	15.8	10	3	82	33	10.9	4	—
Mean	74	77	130	18.5	14	15	77	32	6.4	4	—

* Also tested in 1948.
SOURCE: Compiled from Brunson, Ullstrup and Dicke (1949).

TABLE III. — SUMMARY OF DISEASE AND INSECT RATINGS ON 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948

Inbred line	Helminthosporium			Stewart's wilt, grade	Stalk rot		Smutted plants, %	Kernel rot, grade	European corn borer				Corn ear worm, grade	Leaf aphids, index	Thrips grade
	Carbonum	Turcicum, grade	Maydis, grade		Diplodia, grade	Gibberella, grade			Oviposition, grade	Leaf feeding, grade	Plant injury, grade	Plant tolerance, grade			
ND1	R	5	4	—	3.3	4.5	2	1	3	3	5	5	3.1	4	3
ND5	R	5	5	—	3.8	4.1	14	2	3	4	5	5	2.8	40	4
ND30	R	—	5	—	4.0	3.7	2	1	3	4	5	5	2.5	4	2
ND36	R	5	4	—	4.0	4.2	22	2	3	4	4	5	3.3	0	3
ND167	R	5	3	—	3.1	3.6	4	2	3	3	5	5	2.2	4	1
ND203	R	5	4	—	3.0	3.5	19	2	3	3	5	5	2.4	32	2
ND211	R	—	5	—	4.0	3.6	8	2	4	3	5	5	2.4	0	3
ND230	R	5	3	—	3.8	2.7	9	1	3	3	3	2	1.9	45	3
ND255	R	—	5	—	4.0	4.0	33	1	5	3	5	5	2.5	84	2
ND283	R	5	5	—	3.6	4.4	10	2	3	—	5	5	2.2	0	3
SD102	R	5	3	—	3.0	1.9	30	2	1	4	3	2	3.3	21	2
SD104	R	5	2	—	3.9	4.0	20	2	3	5	3	3	2.3	45	3
SD105	R	5	4	—	3.0	3.7	9	2	3	3	3	3	2.4	64	3
SD106	R	5	2	—	4.0	4.0	23	2	3	3	4	4	2.7	122	2
SD107	R	5	2	—	3.1	3.0	10	2	3	3	3	3	1.5	108	2
C.11	R	5	3	—	2.6	4.0	20	2	3	3	3	3	3.4	98	2
C.11 Imp.	R	5	3	—	2.3	3.3	12	2	3	3	3	3	3.9	100	2
C.14	R	5	1	—	3.5	3.9	14	2	1	4	5	5	1.8	69	3
C.14 Imp.	R	5	1	—	2.9	2.0	9	1	3	3	3	3	1.7	64	3
A7	R	—	2	—	3.5	3.6	15	1	2	4	3	3	2.2	89	3
A12	R	5	5	—	3.2	3.4	13	2	2	3	3	3	2.3	7	2
A15	R	5	3	—	3.6	3.5	1	1	3	3	5	5	1.9	78	1
A21	R	5	3	—	4.0	4.2	6	2	3	3	4	4	2.1	45	3
A25	R	—	4	—	2.0	1.0	7	4	3	1	3	3	2.1	29	2
A34	S	5	4	—	4.0	3.5	2	1	2	3	3	3	3.3	11	2
A71	R	4	1	—	1.9	3.8	5	2	2	3	3	3	2.1	136	3
A73	R	5	3	—	2.0	2.6	7	1	3	3	4	4	2.1	80	4
A90	R	5	1	—	3.8	2.0	18	1	4	4	2	2	2.4	87	2
A96	R	5	2	—	2.6	2.0	4	1	4	3	3	3	2.2	40	1
A111	R	5	5	—	3.7	3.7	6	2	4	4	3	3	3.4	35	2
A116	R	5	3	—	3.0	4.0	1	2	3	3	4	4	2.0	22	3
A131	R	5	3	—	4.0	4.0	4	2	3	4	3	3	.5	15	3
A148	R	5	4	—	2.7	3.2	13	3	1	3	3	3	1.4	56	2
A158	S	5	2	—	1.8	3.4	8	1	3	3	2	2	2.4	92	2
A165	S	5	3	—	2.7	3.3	14	2	3	5	3	4	2.8	19	2
A166	R	5	2	—	3.0	3.9	1	1	3	4	4	4	2.2	12	2
A171	R	5	3	—	3.8	4.5	6	2	5	4	3	3	3.4	30	2

TABLE III. — SUMMARY OF DISEASE AND INSECT RATINGS ON 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948 (*continued*)

Inbred line	Helminthosporium			Stewart's wilt, grade	Stalk rot		Smutted plants, %	Kernel rot, grade	European corn borer				Corn ear worm, grade	Leaf aphids, index	Thrips, grade
	Carbonum	Turcicum, grade	Maydis, grade		Diplodia, grade	Gibberella, grade			Oviposition, grade	Leaf feeding, grade	Plant injury, grade	Plant tolerance, grade			
A188	S	5	3	—	3.3	4.5	11	2	3	3	3	2	2.2	11	2
A311	R	5	3	—	2.6	4.0	11	4	3	3	3	3	2.2	64	2
A322	R	—	2	—	1.6	2.0	6	2	3	1	3	3	2.6	82	3
A334	R	5	5	—	1.8	2.9	2	1	3	3	5	5	2.1	66	2
A340	R	—	4	—	2.3	1.0	17	2	3	3	4	4	2.4	47	2
A344	R	5	3	—	3.9	3.5	7	2	3	4	4	4	2.2	55	1
A347	R	5	2	—	3.3	3.9	0	1	3	3	2	2	2.1	37	2
A357	R	5	4	—	2.5	2.8	8	3	3	3	3	2	2.1	7	3
A374	R	5	3	—	2.7	2.7	10	1	3	3	3	3	2.8	104	1
A375	R	—	3	—	2.1	2.2	2	2	2	3	3	3	2.3	107	1
A385	R	5	3	—	1.8	2.1	4	1	3	3	2	2	2.7	62	1
A392	R	4	3	—	3.2	3.4	5	1	3	2	3	3	2.7	21	4
A395	R	5	4	—	3.0	2.4	6	2	4	3	3	3	2.3	60	1
WR3	R	5	3	—	2.3	3.9	3	2	5	2	2	2	1.2	80	2
W8	R	4.7	4	3	2.0	2.5	3	2	4	1	3	2	2.4	156	1
W9	R	5	3	—	3.4	2.7	7	3	1	4	3	3	1.8	52	1
W16	R	5	2	—	3.0	3.0	0	3	2	1	2	2	2.2	74	2
W17	R	5	3	4	2.3	1.9	12	2	3	3	3	3	2.6	41	2
W20	R	—	2	2	1.9	1.9	3	2	3	3	2	2	2.1	142	3
W22	R	4.7	3	4	2.0	3.5	8	2	3	2	2	2	2.0	139	1
W23	R	5	3	—	3.4	3.4	4	2	3	3	2	2	2.9	96	1
W25	R	5	4	—	2.5	3.4	22	4	5	5	5	5	1.8	75	3
W26	R	5	5	—	2.9	3.1	7	2	3	1	4	4	1.8	46	2
W10	R	—	2	—	4.0	2.9	12	1	3	1	2	2	1.2	90	3
MS206	R	5	2	—	2.8	3.3	10	1	4	5	5	5	2.6	67	2
N6	R	4	2	—	2.3	4.0	1	1	3	3	3	2	1.1	56	1
Ia153	R	4.5	2	—	4.0	3.9	27	4	3	3	4	4	2.2	63	2
I.159	R	5	4	3	3.0	3.4	35	1	3	3	4	4	1.6	115	2
I.205	R	5	3	3	2.0	3.4	3	4	3	3	4	4	1.7	100	3
I.224	R	5	4	4	1.9	3.5	6	1	3	3	3	3	1.8	48	4
I.234	R	4	3	4	2.1	2.5	2	4	3	2	3	2	2.0	83	2
L289	R	4.3	4	—	3.3	3.2	12	2	3	3	3	3	2.4	68	3
Os420	R	5	3	3	3.5	3.3	1	3	5	3	3	3	3.3	64	2
Os426	R	5	1	4	2.6	2.0	28	1	1	3	3	2	3.2	100	1
L317	R	4.7	4	2	2.9	3.0	3	1	4	3	2	2	2.6	55	2

TABLE III. — SUMMARY OF DISEASE AND INSECT RATINGS ON 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948 (*continued*)

Inbred line	Helminthosporium			Stewart's wilt, grade	Stalk rot		Smutted plants, %	Kernel rot, grade	European corn borer				Corn ear worm, grade	Leaf aphids, index	Thrips, grade
	Carbonum	Turcicum, grade	Maydis, grade		Diplodia, grade	Gibberella, grade			Oviposition, grade	Leaf feeding, grade	Plant injury, grade	Plant tolerance, grade			
B8	R	—	2	—	2.5	2.8	5	1	3	3	3	3	2.1	83	3
A	R	—	4	—	2.5	3.2	4	2	3	5	4	4	1.8	100	1
L	R	4	3	2	2.6	2.5	7	1	3	3	3	2	1.9	104	2
90	R	3.3	2	1	2.5	3.9	3	3	3	3	4	4	2.8	64	2
R4	R	5	2	—	2.1	2.5	2	1	3	3	3	3	2.2	72	2
Hy	R	3.5	3	3	2.0	3.0	1	5	3	3	3	3	2.4	66	4
Hy2	R	3.7	3	4	2.9	2.8	0	4	3	2	1	1	2.9	56	3
5120B	R	5	5	3	3.0	1.8	2	5	3	4	3	3	1.9	45	5
M14	R	5	1	—	2.1	3.3	7	3	3	3	4	4	2.5	146	3
4226	R	—	4	—	2.3	2.7	25	2	3	3	3	2	1.6	43	1
R2	R	5	4	3	2.7	4.4	2	4	3	3	4	4	2.4	137	3
R30	R	4	5	2	1.9	2.4	5	1	2	3	3	3	1.6	86	4
R59	R	5	3	3	2.4	3.3	2	2	3	1	3	2	1.6	97	2
R61	R	5	4	3	3.0	2.1	1	2	3	2	2	2	2.8	14	2
66	R	—	4	3	2.9	2.7	5	4	3	3	5	5	2.0	60	3
Tr	R	5	0.5	3	2.2	3.9	9	3	3	3	2	2	2.3	62	3
B164	R	5	3	3	3.2	3.6	12	5	2	5	3	3	2.9	76	1
B2	R	—	2	3	1.7	2.4	11	2	3	3	4	4	2.2	83	2
WF9	R	5	4	4	1.9	2.2	6	1	2	3	4	4	2.2	50	2
38-11	R	5	3	4	3.2	2.2	1	6	3	3	3	3	3.4	113	2
P8	R	5	4	4	1.7	1.5	17	3	3	5	5	2	3.0	103	3
H5	R	5	2	—	2.3	2.6	0	1	3	3	1	1	1.7	87	3
Pr-1	R	3	5	4	2.6	3.0	0	5	3	3	3	2	2.2	60	2
33-16	R	4	2	2	3.1	2.5	0	1	3	4	3	2	1.3	113	2
H21	R	—	4	4	2.9	2.8	8	2	3	3	3	5	2.2	108	3
H22	R	4.5	1	4	3.6	3.3	3	2	3	3	3	3	2.8	191	2
H23	R	2.5	3	2	3.9	3.5	4	1	3	2	2	2	2.1	100	2
Oh02	R	—	3	—	2.9	3.9	1	3	3	4	5	5	1.7	30	3
Oh07	R	5	2	2	2.4	2.1	5	4	3	2	2	2	2.0	88	2
Oh26	R	5	4	—	3.0	3.5	17	3	3	3	5	5	3.0	24	2
Oh28	R	4.5	4	—	2.1	3.4	0	2	2	3	2	2	2.6	7	3
Oh33	R	5	5	3	2.6	2.9	2	5	3	3	3	3	3.2	32	2
Oh40B	R	4	3	—	3.3	3.9	9	3	3	1	1	2	3.5	69	4
Oh51	R	4.7	2	—	1.6	3.2	2	5	3	1	2	2	2.5	100	2
Oh51A	R	5	3	—	2.1	2.9	3	4	2	3	3	3	2.4	87	1
Oh65	R	4.5	2	3	5.0	2.7	8	1	3	—	3	3	3.3	126	1
Oh84	R	—	2	5	3.3	3.0	5	—	3	4	5	5	2.7	189	2
Kys	R	2	3	3	2.8	2.3	2	1	3	3	3	3	2.5	100	3

TABLE III. — SUMMARY OF DISEASE AND INSECT RATINGS ON 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948 (*concluded*)

Inbred line	Helminthosporium			Stewart's wilt, grade	Stalk rot		Smutted plants, %	Kernel rot, grade	European corn borer				Corn ear worm, grade	Leaf aphids, index	Thrips, grade
	Carbonum	Turcicum, grade	Maydis, grade		Diplodia, grade	Gibberella, grade			Oviposition, grade	Leaf feeding, grade	Plant injury, grade	Plant tolerance, grade			
K4	R	4.5	4	—	3.5	2.5	2	2	3	2	4	4	1.8	90	3
K6	R	3	3	1	2.9	3.2	0	4	3	3	4	4	2.4	97	2
K41	R	2.7	4	—	2.7	4.3	3	1	2	3	3	3	1.5	143	3
K44	S	4.7	2	2	3.1	2.2	0	2	4	4	3	3	2.3	100	3
K55	R	5	4	—	2.7	2.4	2	1	4	3	3	3	1.6	118	2
K63	R	4	2	5	3.5	2.4	0	2	3	2	3	3	2.4	122	1
K64	R	4	2	4	4.0	2.1	1	2	3	3	4	4	2.7	104	4
K148	R	1.5	3	2	3.3	1.7	0	5	3	3	2	2	2.9	55	2
K150	R	5	3	3	3.2	2.5	0	4	4	3	3	2	2.1	72	2
K155	R	3	3	—	3.4	2.3	10	1	3	2	3	2	1.3	97	4
K201	R	—	2	—	2.6	2.8	4	3	3	3	5	5	1.1	190	3
Mo.G	R	5	1	—	2.3	2.2	6	5	3	3	3	2	2.4	100	2
Mo.L3	R	3	4	—	3.4	2.8	1	1	3	3	2	3	1.4	71	2
Mo.2RF	R	3	2	3	2.4	2.7	0	1	2	3	3	3	2.7	41	2
Mo.22	R	3	2	—	2.0	1.0	1	2	3	3	1	1	2.1	118	3
Ky21	R	3	3	3	2.4	1.8	3	2	4	3	3	3	1.7	159	2
Ky27	R	2	1	2	3.4	3.4	0	1	3	3	4	4	2.1	86	1
Ky39	R	2.5	3	2	2.8	3.6	1	2	3	4	3	3	1.5	111	4
Ky49	R	4.5	2	4	3.4	3.5	15	1	3	4	5	5	2.2	108	3
Ky58	R	3	2	—	3.0	3.5	8	1	4	3	3	3	2.2	73	2
Ky122	R	2	4	4	3.4	2.3	17	1	4	3	4	3	2.5	104	3
T18	R	2.6	4	—	3.6	2.0	24	2	3	3	2	2	1.6	100	3
4-8	R	4	2	4	2.8	4.5	1	—	3	4	3	3	1.6	120	4
540	R	5	3	4	2.1	2.9	0	1	3	3	4	4	2.2	46	3
187-2	R	5	3	5	2.8	3.4	6	3	3	3	5	5	4.1	7	2
Cl.2	R	2	3	4	3.6	4.1	0	1	3	3	3	3	1.2	100	2
Cl.3	R	4	3	2	2.1	3.1	6	1	4	3	4	4	2.0	100	2
Cl.3A	R	4	3	2	3.3	3.3	0	1	3	3	5	5	1.7	105	3
Cl.5	R	3	3	3	3.1	1.9	5	—	3	2	4	4	1.9	130	2
Cl.7	R	4.7	3	2	3.9	3.0	7	1	3	3	3	3	1.2	185	2
Cl.11b	R	3	3	4	3.2	2.5	0	1	3	3	4	4	1.3	69	3
Cl.23	R	1	4	—	2.6	3.9	10	1	3	1	3	3	1.5	114	3
Cl.41	R	3	2	4	2.9	2.7	0	1	3	3	3	3	1.9	100	3
Cl.43	R	2.3	3	—	3.6	4.1	4	1	3	1	2	2	1.5	100	2
Cl.61	R	5	3	5	3.1	2.5	0	1	3	2	4	4	1.8	121	1

SOURCE: Compiled from Brunson, Ullstrup and Dicke (1948).
NOTE: The smallest grade, percentage or index is the most resistant.

TABLE IV. — SUMMARY OF DISEASE AND INSECT RATINGS ON 89 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1949

Inbred line	Helminthosporium			Stewart's wilt, grade	Stalk rot		Smut, %	Kernel rot, grade	European corn borer			Corn ear worm, grade	Leaf aphids, index	Flea beetle, grade
	Carbonum	Turcicum, grade	Maydis, grade		Diplodia, grade	Gibberella, grade			Oviposition, grade	Plant injury, grade	Plant tolerance, grade			
ND36	R	—	5	5	—	—	37	3	3	3.0	5	—	0	2.7
ND230	R	—	5	4	—	—	0	1	3	4.5	4	—	0	2.0
SD105	R	—	5	4	—	—	14	2	3	3.5	3	—	0	1.7
SD107	R	—	4	4	—	—	0	2	3	4.5	4	—	0	2.0
A25	R	—	4	1	—	—	27	3	3	4.0	2	—	0	3.3
A71	R	1	2	0	—	—	0	2	3	3.5	2	—	0	3.3
A73	R	4	4	2	—	—	0	2	2	4.0	4	—	0	2.7
A96	R	—	4	5	—	—	5	1	4	3.0	3	—	0	1.3
WR3	R	—	4	3	—	—	4	2	3	2.5	3	—	0	2.7
W22	R	3	4	3	—	—	17	1	3	2.0	2	—	0	3.0
W32	R	3	3	0.5	—	—	0	2	4	4.0	3	—	7.4	3.3
W38	R	3	3	1	—	—	0	1	2	1.5	2	—	0	4.0
W62	R	5	4	1	—	—	16	2	3	4.5	3	—	0	3.7
W70	R	5	4	1	—	—	7	2	3	3.5	3	—	3.3	3.7
W74	R	5	3	1	—	—	7	2	3	4.0	3	—	0	3.0
W136	R	4	2	2	—	—	0	3	3	2.5	2	—	0	3.0
W146	R	4	2	3	—	—	21	1	5	3.5	4	—	0	1.3
W164	R	5	4	1	—	—	0	2	3	4.0	3	—	0	3.0
MS1	R	3	3	1	—	—	0	1	3	2.5	2	—	16.7	3.7
MS19	R	5	5	3	—	—	37	2	3	5.0	4	—	5.0	2.7
MS24	R	5	5	3	—	—	10	1	3	2.5	4	—	0	1.0
N1	R	3	3	2	1.0	1.0	3	3	5	1.5	2	—	30.0	2.7
N2	R	3	3	3	2.6	4.0	0	1	3	2.5	2	26	100.0	2.7
Ia.153	R	3	4	2	2.0	2.6	61	1	3	4.0	5	—	0	2.3
L205	R	2	4	1	1.4	1.6	4	2	3	3.5	3	—	4.0	3.0
L304A	R	4	5	2	2.4	2.4	10	1	3	2.5	4	8	40.0	1.0
L317	R	3	4	0.5	1.0	1.6	0	1	3	2.0	2	9	6.7	2.3
Os420	R	2	4	2	1.0	1.4	40	2	4	2.5	3	—	0	2.7

TABLE IV. — SUMMARY OF DISEASE AND INSECT RATINGS ON 89 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1949 (*continued*)

Inbred line	Helminthosporium			Stewart's wilt, grade	Stalk rot		Smut, %	Kernel rot, grade	European corn borer			Corn ear worm, grade	Leaf aphids, index	Flea beetle, grade
	Carbonum	Turcicum, grade	Maydis, grade		Diplodia, grade	Gibberella, grade			Oviposition, grade	Plant injury, grade	Plant tolerance, grade			
B6	R	5	4	1	1.4	1.6	0	1	3	4.0	3	7	0	3.0
B7	R	3	4	1	1.8	1.0	0	2	2	2.0	3	12	0	2.3
B8	R	5	4	4	1.6	1.0	0	3	3	3.5	3	—	0	1.3
B14	R	5	3	4	2.4	2.4	0	2	3	4.5	3	3	7.1	1.3
B32	R	3	3	4	2.6	2.2	0	2	2	4.5	2	20	86.7	2.0
M14	R	3	2	1	5.0	1.0	3	2	4	4.5	4	10	0	2.0
A	R	5	5	2	0.5	1.5	3	1	3	5.0	4	12	3.3	3.0
Hy2	R	4	5	1	1.4	2.2	0	2	2	2.0	2	14	3.4	2.3
R30	R	5	5	1	1.0	4.2	0	2	5	2.5	2	13	0	2.3
L5	R	4	3	0.5	1.0	1.0	39	3	3	2.0	1	17	3.3	3.7
L13	R	4	4	3	1.2	1.0	0	2	3	3.0	3	17	42.9	3.0
L17	R	5	4	1	2.0	3.4	0	1	4	4.0	2	15	3.4	3.0
L18	R	5	4	2	1.0	1.0	0	5	4	4.5	4	32	13.8	3.0
L29	R	3	3	1	1.2	1.0	7	3	3	3.0	2	19	27.6	3.7
L30	R	3	3	2	—	5.0	6	3	3	3.0	3	35	10.0	3.7
L34	R	5	3	1	—	5.0	23	3	5	3.0	3	5	23.3	3.0
L39	R	3	2	1	3.0	4.0	0	3	1	3.0	2	44	0	3.7
54-14	R	5	5	4	1.8	5.0	45	4	3	3.0	3	39	0	2.3
WF9	R	3	5	1	2.8	4.5	4	3	1	4.0	3	27	10.7	3.0
Tr	R	4	0.5	2	—	4.0	24	3	3	4.0	3	28	3.3	2.3
T92	R	3	2	2	4.0	3.0	0	4	3	5.0	2	10	16.7	3.3
T96	R	3	2	0.5	1.4	1.0	19	3	2	4.5	3	36	32.1	3.7
38-11	R	3	3	2	2.0	2.0	7	4	2	3.0	2	19	50.0	2.0
P8	S	3	5	0.5	1.2	1.0	3	3	3	4.0	2	—	20.7	1.7
33-16	R	2	2	0.5	1.4	1.4	7	2	3	2.5	2	—	44.8	3.0
H21	R	2	5	0.5	2.6	2.6	24	3	3	1.5	2	14	16.7	3.0
H25	R	3	5	1	—	4.5	3	2	3	4.0	2	19	100.0	2.0
Oh07	R	2	3	1	1.0	1.8	8	2	3	2.5	3	8	50.0	2.3
Oh7B	R	3	4	2	1.4	1.0	0	2	3	2.0	2	—	85.0	2.0
Oh26	R	—	5	0	2.4	1.5	5	3	3	5.0	4	27	5.3	3.0
Oh28	R	3	4	0.5	3.0	2.0	6	2	1	4.0	4	—	10.0	2.0
Oh29	R	—	3	1	4.0	4.0	0	2	2	3.0	2	4	56.7	2.0
Oh40B	R	3	2	2	4.0	4.0	3	3	2	1.0	4	—	0	2.7
Oh41	R	2	3	1	3.0	3.0	3	1	4	1.5	2	7	0	2.7
Oh43	R	—	1	1	4.0	4.0	0	2	3	1.5	3	—	0	3.0

TABLE IV. — SUMMARY OF DISEASE AND INSECT RATINGS ON 89 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1949 (*concluded*)

Inbred line	Helminthosporium			Stewart's wilt, grade	Stalk rot		Smut, %	Kernel rot, grade	European corn borer			Corn ear worm, grade	Leaf aphids, index	Flea beetle, grade
	Carbonum	Turcicum, grade	Maydis, grade		Diplodia, grade	Gibberella, grade			Oviposition, grade	Plant injury, grade	Plant tolerance, grade			
Oh45	R	3	1	0.5	4.0	4.0	3	3	3	1.5	2	—	0	3.7
Oh51A	R	3	4	0.5	2.0	1.0	0	4	3	3.0	3	7	0	3.3
Oh56A	S	5	4	0.5	2.0	5.0	10	3	4	4.0	4	50	0	2.7
C103	R	0.5	0.5	0	3.0	3.0	0	4	3	3.0	3	10	0	2.3
Kys	R	1	3	1	1.8	4.2	0	—	2	2.0	2	—	10.0	1.7
K4	R	1	4	0.5	1.8	4.6	0	—	3	3.5	2	33	26.7	3.7
K41	R	1	4	2	2.4	2.4	0	—	3	3.5	3	—	80.0	2.0
K44	S	3	3	1	2.8	2.8	0	—	5	2.5	2	—	55.2	2.7
K61	S	3	4	0	—	4.8	7	—	2	1.5	3	16	56.7	3.7
K64	R	3	1	2	4.6	1.2	0	—	3	3.0	2	10	76.9	1.0
K201	R	1	2	0	1.0	1.0	12	—	2	5.0	5	3	92.3	2.0
Mo.557	R	2	1	1	1.0	2.8	10	—	4	2.0	2	13	0	2.3
Mo.567	R	2	2	0.5	1.0	4.0	0	—	2	2.5	2	4	69.0	3.0
Mo.572	R	3	3	0.5	—	—	0	—	3	3.0	3	16	21.4	2.0
Mo.577	R	2	1	1	—	—	13	—	5	1.5	2	—	29.0	1.3
Mo.580	R	2	4	0.5	—	—	22	—	4	2.5	4	17	40.7	2.0
Ky27	R	1	2	0.5	—	—	0	—	3	4.0	3	18	69.2	2.3
Ky122	R	0.5	5	2	—	—	22	—	2	1.5	2	16	74.1	2.3
Ky36-11	R	2	3	1	—	—	4	—	4	2.0	3	5	78.6	2.3
T8	R	3	1	1	—	—	3	—	2	3.0	3	—	100.0	3.7
Cl.7	R	3	2	1	—	—	3	—	3	2.0	2	21	13.3	3.0
Cl.187-2	R	3	4	0.5	—	—	0	—	5	4.0	4	13	0	3.3
Cl.21	R	3	2	0.5	—	—	0	—	4	3.0	2	—	100.0	2.3
Cl.21E	R	3	2	0.5	—	—	3	—	3	3.0	2	17	100.0	2.3
Cl.27	R	2	2	0.5	3.0	3.6	10	—	3	3.0	3	7	79.3	1.7
K64 (rec.)	R	1	1	0.5	3.0	3.0	7	—	4	2.0	3	9	60.0	2.3

SOURCE: Compiled from Brunson, Ullstrup and Dicke (1949).
NOTE: The smallest grade, percentage or index is the most resistant.

TABLE V. — SUMMARY OF CHEMICAL COMPOSITION OF 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948

Inbred line	Weight [1] per 1,000 seeds, grams	Protein [2], %	Alcohol [2] soluble nitrogen, %	Oil [2], %
ND1	211	13.9	1.11	4.6
ND5	223	11.6	0.96	4.7
ND30	163	15.6	1.42	5.8
ND36	191	11.9	1.14	5.2
ND167	146	14.0	1.24	4.2
ND203	201	15.0	1.35	4.2
ND211	173	13.3	1.09	3.8
ND230	195	12.6	1.14	5.1
ND255	162	15.2	1.41	4.3
ND283	184	16.1	1.44	4.8
SD102	211	11.9	0.99	3.4
SD104	196	13.5	1.26	4.2
SD105	183	14.0	1.34	5.1
SD106	223	15.2	1.66	4.0
SD107	170	12.0	1.14	3.7
C.11	226	12.6	1.22	4.6
C.11 Imp.	228	12.9	1.29	4.6
C.14	141	16.1	1.70	4.8
C.14 Imp.	159	14.5	1.47	4.9
A7	174	14.4	1.25	4.3
A12	166	14.5	1.24	4.3
A15	133	12.5	1.05	4.4
A21	159	15.2	1.58	4.4
A25	178	11.4	0.89	4.3
A34	221	12.3	1.09	4.8
A71	257	11.9	0.98	5.2
A73	208	10.2	0.82	4.9
A90	187	13.8	1.34	4.3
A96	210	13.4	1.27	5.1
A111	119	13.7	1.29	4.1
A116	213	13.1	1.23	4.2
A131	185	13.5	1.36	4.3
A148	200	13.5	1.21	5.5
A158	175	11.2	1.02	5.4
A165	212	13.1	1.14	4.7
A166	187	12.0	1.14	4.0
A171	209	12.2	1.15	4.8
A188	223	13.4	1.13	4.9
A311	199	12.0	1.07	4.6

For notes, see end of Table V, page 335.

TABLE V. — SUMMARY OF CHEMICAL COMPOSITION OF 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948 (*continued*)

Inbred line	Weight [1] per 1,000 seeds, grams	Protein [2], %	Alcohol [2] soluble nitrogen, %	Oil [2], %
A322	238	11.0	1.01	4.4
A334	213	13.3	1.11	4.9
A340	218	13.1	1.08	4.9
A344	210	13.2	1.34	4.9
A347	193	12.8	1.34	4.3
A357	194	11.1	0.94	4.2
A374	231	12.9	1.09	4.7
A375	186	13.2	1.16	4.6
A385	198	13.6	1.37	4.7
A392	154	11.6	1.00	4.5
A395	191	11.1	0.83	4.7
WR3	206	10.8	0.88	5.5
W8	216	10.1	0.76	5.1
W9	178	12.8	1.19	4.4
W16	192	12.6	1.16	4.8
W17	201	11.6	0.98	5.4
W20	247	12.1	0.96	4.6
W22	227	11.7	0.97	4.5
W23	150	10.0	0.76	4.9
W25	273	15.1	1.33	5.3
W26	222	13.7	1.04	4.7
W10	238	13.4	1.26	4.6
MS206	246	13.2	1.22	4.3
N6	208	12.1	0.97	5.3
Ia153	193	14.1	1.40	4.2
I.159	294	11.3	0.87	5.0
I.205	260	11.2	0.88	3.6
I.224	266	12.5	1.40	3.8
I.234	325	9.8	0.74	4.1
L289	177	12.1	0.75	3.5
Os420	245	11.6	0.75	3.9
Os426	256	12.3	0.97	3.8
L317	197	12.4	1.05	4.6
B8	213	10.8	0.94	4.5
A	159	12.9	1.09	4.7
L	287	11.5	0.90	4.7

TABLE V. — SUMMARY OF CHEMICAL COMPOSITION OF 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948 (*continued*)

Inbred line	Weight [1] per 1,000 seeds, grams	Protein [2], %	Alcohol [2] soluble nitrogen, %	Oil [2], %
90	180	13.2	1.29	4.2
R4	164	13.0	1.09	4.0
Hy	219	11.0	0.90	3.6
Hy2	229	10.1	0.82	3.6
5120B	333	11.1	0.83	5.0
M14	230	12.1	1.00	5.3
4226	189	12.2	0.90	4.8
R2	224	11.7	1.02	3.6
R30	259	11.1	0.86	5.6
R59	247	11.7	1.01	3.7
R61	240	11.4	0.92	4.2
66	251	10.3	0.79	3.7
TR	237	10.3	0.65	3.5
B164	217	10.2	0.77	4.3
B2	236	12.9	0.98	4.3
WF9	224	11.6	0.85	4.5
38-11	244	12.6	1.16	5.5
P8	213	12.1	1.23	4.6
H5	193	13.3	1.10	3.8
Pr-1	216	11.3	0.87	4.4
33-16	248	11.6	0.83	4.2
H21	245	11.4	0.87	3.8
H22	299	10.9	0.78	4.8
H23	312	13.3	1.20	4.2
Oh02	188	12.1	1.09	2.7
Oh07	263	11.0	0.91	5.0
Oh26	267	12.8	0.96	5.2
Oh28	206	10.4	0.84	3.7
Oh33	212	11.9	0.99	3.7
Oh40B	258	11.6	0.94	5.2
Oh51	207	10.2	0.90	4.8
Oh510	257	10.9	0.78	5.2
Oh65	244	14.3	1.28	4.9
Oh84	249	12.1	0.96	5.7
Kys	214	13.3	1.17	4.9
K4	195	12.1	1.03	5.8

TABLE V. — SUMMARY OF CHEMICAL COMPOSITION OF 145 INBRED LINES GROWN IN THE NORTH-CENTRAL SECTION OF THE UNITED STATES, 1948 (*concluded*)

Inbred line	Weight [1] per 1,000 seeds, grams	Protein [2], %	Alcohol [2] soluble nitrogen, %	Oil [2], %
K6	283	12.6	1.16	3.7
K41	185	12.5	1.07	4.9
K44	252	9.7	0.78	4.9
K55	247	13.3	1.04	5.1
K63	257	14.0	1.18	5.1
K64	287	11.2	0.90	4.2
K148	229	12.5	1.02	4.5
K150	264	10.8	0.93	4.5
K155	252	10.9	0.85	5.4
K201	370	12.6	1.02	5.5
Mo.G	214	10.9	0.81	4.9
Mo.L3	205	12.0	0.94	4.6
Mo.2RF	261	10.7	0.79	4.0
Mo.22	213	13.0	1.39	4.7
Ky21	295	11.7	0.98	4.2
Ky27	225	10.5	0.87	4.3
Ky39	288	10.8	0.81	4.1
Ky49	312	12.3	1.00	4.0
Ky58	193	13.0	1.22	4.7
Ky122	221	13.2	1.24	4.5
T18	268	13.1	1.08	5.8
4-8	216	14.6	1.34	4.9
540	185	12.3	1.00	4.9
187-2	235	11.2	0.95	4.9
Cl.2	237	15.3	1.38	4.8
Cl.3	202	12.5	0.94	4.0
Cl.3A	257	11.8	0.86	4.3
Cl.5	307	13.6	1.11	5.3
Cl.7	258	12.5	0.97	4.0
Cl.11B	230	12.4	1.03	4.2
Cl.23	290	14.0	1.30	4.8
Cl.41	323	13.9	1.24	4.4
Cl.43	276	12.9	1.14	3.7
Cl.61	318	13.5	1.31	3.9

[1] Weight per 1,000 seeds on an air-dry basis. — [2] Chemical analyses on moisture-free basis.

SOURCE: Analyses by the Northern Utilization Research Branch, U.S. Department of Agriculture, Peoria, Illinois.

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
1	(0x1) x (2x3)	0x2,	0x3,	1x2,	1x3
2	(0x1) x (2x4)	0x2,	0x4,	1x2,	1x4
3	(0x1) x (2x5)	0x2,	0x5,	1x2,	1x5
4	(0x1) x (2x6)	0x2,	0x6,	1x2,	1x6
5	(0x1) x (2x7)	0x2,	0x7,	1x2,	1x7
6	(0x1) x (2x8)	0x2,	0x8,	1x2,	1x8
7	(0x1) x (2x9)	0x2,	0x9,	1x2,	1x9
8	(0x1) x (3x4)	0x3,	0x4,	1x3	1x4
9	(0x1) x (3x5)	0x3,	0x5,	1x3,	1x5
10	(0x1) x (3x6)	0x3,	0x6,	1x3,	1x6
11	(0x1) x (3x7)	0x3,	0x7,	1x3,	1x7
12	(0x1) x (3x8)	0x3,	0x8,	1x3,	1x8
13	(0x1) x (3x9)	0x3,	0x9,	1x3,	1x9
14	(0x1) x (4x5)	0x4,	0x5,	1x4,	1x5
15	(0x1) x (4x6)	0x4,	0x6,	1x4,	1x6
16	(0x1) x (4x7)	0x4,	0x7,	1x4,	1x7
17	(0x1) x (4x8)	0x4,	0x8,	1x4,	1x8
18	(0x1) x (4x9)	0x4,	0x9,	1x4,	1x9
19	(0x1) x (5x6)	0x5,	0x6,	1x5,	1x6
20	(0x1) x (5x7)	0x5,	0x7,	1x5,	1x7
21	(0x1) x (5x8)	0x5,	0x8,	1x5,	1x8
22	(0x1) x (5x9)	0x5,	0x9,	1x5,	1x9
23	(0x1) x (6x7)	0x6,	0x7,	1x6,	1x7
24	(0x1) x (6x8)	0x6,	0x8,	1x6,	1x8
25	(0x1) x (6x9)	0x6,	0x9,	1x6,	1x9
26	(0x1) x (7x8)	0x7,	0x8,	1x7,	1x8
27	(0x1) x (7x9)	0x7,	9x9,	1x7,	1x9
28	(0x1) x (8x9)	0x8,	0x9,	1x8,	1x9
29	(0x2) x (1x3)	0x1,	0x3,	2x1,	2x3
30	(0x2) x (1x4)	0x1,	0x4,	2x1,	2x4
31	(0x2) x (1x5)	0x1,	0x5,	2x1,	2x5
32	(0x2) x (1x6)	0x1,	0x6,	2x1,	2x6
33	(0x2) x (1x7)	0x1,	0x7,	2x1,	2x7
34	(0x2) x (1x8)	0x1,	0x8,	2x1,	2x8
35	(0x2) x (1x9)	0x1,	0x9,	2x1,	2x9
36	(0x2) x (3x4)	0x3,	0x4,	2x3,	2x4
37	(0x2) x (3x5)	0x3,	0x5,	2x3,	2x5
38	(0x2) x (3x6)	0x3,	0x6,	2x3,	2x6
39	(0x2) x (3x7)	0x3,	0x7,	2x3,	2x7
40	(0x2) x (3x8)	0x3,	0x8,	2x3,	2x8
41	(0x2) x (3x9)	0x3,	0x9,	2x3,	2x9
42	(0x2) x (4x5)	0x4,	0x5,	2x4,	2x5
43	(0x2) x (4x6)	0x4,	0x6,	2x4,	2x6
44	(0x2) x (4x7)	0x4,	0x7,	2x4,	2x7
45	(0x2) x (4x8)	0x4,	0x8,	2x4,	2x8
46	(0x2) x (4x9)	0x4,	0x9,	2x4,	2x9
47	(0x2) x (5x6)	0x5,	0x6,	2x5,	2x6
48	(0x2) x (5x7)	0x5,	0x7,	2x5,	2x7
49	(0x2) x (5x8)	0x5,	0x8,	2x5,	2x8
50	(0x2) x (5x9)	0x5,	0x9,	2x5,	2x9
51	(0x2) x (6x7)	0x6,	0x7,	2x6,	2x7
52	(0x2) x (6x8)	0x6,	0x8,	2x6,	2x8
53	(0x2) x (6x9)	0x6,	0x9,	2x6,	2x9
54	(0x2) x (7x8)	0x7,	0x8,	2x7,	2x8
55	(0x2) x (7x9)	0x7,	0x9,	2x7,	2x9
56	(0x2) x (8x9)	0x8,	0x9,	2x8,	2x9
57	(0x3) x (1x2)	0x1,	0x2,	3x1,	3x2
58	(0x3) x (1x4)	0x1,	0x4,	3x1,	3x4
59	(0x3) x (1x5)	0x1,	0x5,	3x1,	3x5
60	(0x3) x (1x6)	0x1,	0x6,	3x1,	3x6

NOTE: See Chapter 17, "Predicting the Performance of Hybrids" for procedure.

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS (*continued*)

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
61	(0x3) x (1x7)	0x1,	0x7,	3x1,	3x7
62	(0x3) x (1x8)	0x1,	0x8	3x1,	3x8
63	(0x3) x (1x9)	0x1,	0x9,	3x1,	3x9
64	(0x3) x (2x4)	0x2,	0x4,	3x2,	3x4
65	(0x3) x (2x5)	0x2,	0x5,	3x2,	3x5
66	(0x3) x (2x6)	0x2,	0x6,	3x2,	3x6
67	(0x3) x (2x7)	0x2,	0x7,	3x2,	3x7
68	(0x3) x (2x8)	0x2,	0x8,	3x2,	3x8
69	(0x3) x (2x9)	0x2,	0x9,	3x2,	3x9
70	(0x3) x (4x5)	0x4,	0x5,	3x4,	3x5
71	(0x3) x (4x6)	0x4,	0x6,	3x4,	3x6
72	(0x3) x (4x7)	0x4,	0x7,	3x4,	3x7
73	(0x3) x (4x8)	0x4,	0x8,	3x4,	3x8
74	(0x3) x (4x9)	0x4,	0x9,	3x4,	3x9
75	(0x3) x (5x6)	0x5,	0x6,	3x5,	3x6
76	(0x3) x (5x7)	0x5,	0x7,	3x5,	3x7
77	(0x3) x (5x8)	0x5,	0x8,	3x5,	3x8
78	(0x3) x (5x9)	0x5,	0x9,	3x5,	3x9
79	(0x3) x (6x7)	0x6,	0x7,	3x6,	3x7
80	(0x3) x (6x8)	0x6,	0x8,	3x6,	3x8
81	(0x3) x (6x9)	0x6,	0x9,	3x6,	3x9
82	(0x3) x (7x8)	0x7,	0x8,	3x7,	3x8
83	(0x3) x (7x9)	0x7,	0x9,	3x7,	3x9
84	(0x3) x (8x9)	0x8,	0x9,	3x8,	3x9
85	(0x4) x (1x2)	0x1,	0x2,	4x1,	4x2
86	(0x4) x (1x3)	0x1,	0x3,	4x1,	4x3
87	(0x4) x (1x5)	0x1,	0x5,	4x1,	4x5
88	(0x4) x (1x6)	0x1,	0x6,	4x1,	4x6
89	(0x4) x (1x7)	0x1,	0x7,	4x1,	4x7
90	(0x4) x (1x8)	0x1,	0x8,	4x1,	4x8
91	(0x4) x (1x9)	0x1,	0x9,	4x1,	4x9
92	(0x4) x (2x3)	0x2,	0x3,	4x2,	4x3
93	(0x4) x (2x5)	0x2,	0x5,	4x2,	4x5
94	(0x4) x (2x6)	0x2,	0x6,	4x2,	4x6
95	(0x4) x (2x7)	0x2,	0x7,	4x2,	4x7
96	(0x4) x (2x8)	0x2,	0x8,	4x2,	4x8
97	(0x4) x (2x9)	0x2,	0x9,	4x2,	4x9
98	(0x4) x (3x5)	0x3,	0x5,	4x3,	4x5
99	(0x4) x (3x6)	0x3,	0x6,	4x3,	4x6
100	(0x4) x (3x7)	0x3,	0x7,	4x3,	4x7
101	(0x4) x (3x8)	0x3,	0x8,	4x3,	4x8
102	(0x4) x (3x9)	0x3,	0x9,	4x3,	4x9
103	(0x4) x (5x6)	0x5,	0x6,	4x5,	4x6
104	(0x4) x (5x7)	0x5,	0x7,	4x5,	4x7
105	(0x4) x (5x8)	0x5,	0x8,	4x5,	4x8
106	(0x4) x (5x9)	0x5,	0x9,	4x5,	4x9
107	(0x4) x (6x7)	0x6,	0x7,	4x6,	4x7
108	(0x4) x (6x8)	0x6,	0x8,	4x6,	4x8
109	(0x4) x (6x9)	0x6,	0x9,	4x6,	4x9
110	(0x4) x (7x8)	0x7,	0x8,	4x7,	4x8
111	(0x4) x (7x9)	0x7,	0x9,	4x7,	4x9
112	(0x4) x (8x9)	0x8,	0x9,	4x8,	4x9
113	(0x5) x (1x2)	0x1,	0x2,	5x1,	5x2
114	(0x5) x (1x3)	0x1,	0x3,	5x1,	5x3
115	(0x5) x (1x4)	0x1,	0x4,	5x1,	5x4
116	(0x5) x (1x6)	0x1,	0x6,	5x1,	5x6
117	(0x5) x (1x7)	0x1,	0x7,	5x1,	5x7
118	(0x5) x (1x8)	0x1,	0x8,	5x1,	5x8
119	(0x5) x (1x9)	0x1,	0x9,	5x1,	5x9
120	(0x5) x (2x3)	0x2,	0x3,	5x2,	5x3

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS (*continued*)

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
121	(0x5) x (2x4)	0x2,	0x4,	5x2,	5x4
122	(0x5) x (2x6)	0x2,	0x6,	5x2,	5x6
123	(0x5) x (2x7)	0x2,	0x7,	5x2,	5x7
124	(0x5) x (2x8)	0x2,	0x8,	5x2,	5x8
125	(0x5) x (2x9)	0x2,	0x9,	5x2,	5x9
126	(0x5) x (3x4)	0x3,	0x4,	5x3,	5x4
127	(0x5) x (3x6)	0x3,	0x6,	5x3,	5x6
128	(0x5) x (3x7)	0x3,	0x7,	5x3,	5x7
129	(0x5) x (3x8)	0x3,	0x8,	5x3,	5x8
130	(0x5) x (3x9)	0x3,	0x9,	5x3,	5x9
131	(0x5) x (4x6)	0x4,	0x6,	5x4,	5x6
132	(0x5) x (4x7)	0x4,	0x7,	5x4,	5x7
133	(0x5) x (4x8)	0x4,	0x8,	5x4,	5x8
134	(0x5) x (4x9)	0x4,	0x9,	5x4.	5x9
135	(0x5) x (6x7)	0x6,	0x7,	5x6,	5x7
136	(0x5) x (6x8)	0x6,	0x8,	5x6,	5x8
137	(0x5) x (6x9)	0x6,	0x9,	5x6,	5x9
138	(0x5) x (7x8)	0x7,	0x8,	5x7,	5x8
139	(0x5) x (7x9)	0x7,	0x9,	5x7,	5x9
140	(0x5) x (8x9)	0x8,	0x9,	5x8,	5x9
141	(0x6) x (1x2)	0x1,	0x2,	6x1,	6x2
142	(0x6) (1x3)	0x1,	0x3,	6x1,	6x3
143	(0x6) x (1x4)	0x1,	0x4,	6x1,	6x4
144	(0x6) x (1x5)	0x1,	0x5,	6x1	6x5
145	(0x6) x (1x7)	0x1,	0x7,	6x1,	6x7
146	(0x6) x (1x8)	0x1,	0x8,	6x1,	6x8
147	(0x6) x (1x9)	0x1,	0x9,	6x1,	6x9
148	(0x6) x (2x3)	0x2,	0x3,	6x2	6x3
149	(0x6) x (2x4)	0x2,	0x4,	6x2,	6x4
150	(0x6) x (2x5)	0x2,	0x5,	6x2,	6x5
151	(0x6) x (2x7)	0x2,	0x7,	6x2,	6x7
152	(0x6) x (2x8)	0x2,	0x8,	6x2,	6x8
153	(0x6) x (2x9)	0x2,	0x9,	6x2,	6x9
154	(0x6) x (3x4)	0x3,	0x4,	6x3,	6x4
155	(0x6) x (3x5)	0x3,	0x5,	6x3,	6x5
156	(0x6) x (3x7)	0x3,	0x7,	6x3,	6x7
157	(0x6) x (3x8)	0x3,	0x8,	6x3,	6x8
158	(0x6) x (3x9)	0x3,	0x9	6x3,	6x9
159	(0x6) x (4x5)	0x4,	0x5,	6x4,	6x5
160	(0x6) x (4x7)	0x4,	0x7,	6x4,	6x7
161	(0x6) x (4x8)	0x4,	0x8,	6x4,	6x8
162	(0x6) x (4x9)	0x4,	0x9,	6x4,	6x9
163	(0x6) x (5x7)	0x5,	0x7,	6x5,	6x7
164	(0x6) x (5x8)	0x5,	0x8,	6x5,	6x8
165	(0x6) x (5x9)	0x5,	0x9,	6x5,	6x9
166	(0x6) x (7x8)	0x7,	0x8,	6x7,	6x8
167	(0x6) x (7x9)	0x7,	0x9,	6x7,	6x9
168	(0x6) x (8x9)	0x8,	0x9,	6x8,	6x9
169	(0x7) x (1x2)	0x1,	0x2,	7x1,	7x2
170	(0x7) x (1x3)	0x1,	0x3,	7x1,	7x3
171	(0x7) x (1x4)	0x1,	0x4,	7x1,	7x4
172	(0x7) x (1x5)	0x1,	0x5,	7x1,	7x5
173	(0x7) x (1x6)	0x1,	0x6,	7x1,	7x6
174	(0x7) x (1x8)	0x1,	0x8,	7x1,	7x8
175	(0x7) x (1x9)	0x1,	0x9,	7x1,	7x9
176	(0x7) x (2x3)	0x2,	0x3,	7x2,	7x3
177	(0x7) x (2x4)	0x2,	0x4,	7x2,	7x4
178	(0x7) x (2x5)	0x2,	0x5,	7x2,	7x5
179	(0x7) x (2x6)	0x2,	0x6,	7x2,	7x6
180	(0x7) x (2x8)	0x2,	0x8,	7x2,	7x8

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS (*continued*)

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
181	(0x7) x (2x9)	0x2,	0x9,	7x2,	7x9
182	(0x7) x (3x4)	0x3,	0x4,	7x3,	7x4
183	(0x7) x (3x5)	0x3,	0x5,	7x3,	7x5
184	(0x7) x (3x6)	0x3,	0x6,	7x3,	7x6
185	(0x7) x (3x8)	0x3,	0x8,	7x3,	7x8
186	(0x7) x (3x9)	0x3,	0x9,	7x3,	7x9
187	(0x7) x (4x5)	0x4,	0x5,	7x4,	7x5
188	(0x7) x (4x6)	0x4,	0x6,	7x4,	7x6
189	(0x7) x (4x8)	0x4,	0x8,	7x4,	7x8
190	(0x7) x (4x9)	0x4,	0x9,	7x4,	7x9
191	(0x7) x (5x6)	0x5,	0x6,	7x5,	7x6
192	(0x7) x (5x8)	0x5,	0x8,	7x5,	7x8
193	(0x7) x (5x9)	0x5,	0x9,	7x5,	7x9
194	(0x7) x (6x8)	0x6,	0x8,	7x6,	7x8
195	(0x7) x (6x9)	0x6,	0x9,	7x6,	7x9
196	(0x7) x (8x9)	0x8,	0x9,	7x8,	7x9
197	(0x8) x (1x2)	0x1,	0x2,	8x1,	8x2
198	(0x8) x (1x3)	0x1,	0x3,	8x1,	8x3
199	(0x8) x (1x4)	0x1,	0x4,	8x1,	8x4
200	(0x8) x (1x5)	0x1,	0x5,	8x1,	8x5
201	(0x8) x (1x6)	0x1,	0x6,	8x1,	8x6
202	(0x8) x (1x7)	0x1,	0x7,	8x1,	8x7
203	(0x8) x (1x9)	0x1,	0x9,	8x1,	8x9
204	(0x8) x (2x3)	0x2,	0x3,	8x2,	8x3
205	(0x8) x (2x4)	0x2,	0x4,	8x2,	8x4
206	(0x8) x (2x5)	0x2,	0x5,	8x2,	8x5
207	(0x8) x (2x6)	0x2,	0x6,	8x2,	8x6
208	(0x8) x (2x7)	0x2,	0x7,	8x2,	8x7
209	(0x8) x (2x9)	0x2,	0x9,	8x2,	8x9
210	(0x8) x (3x4)	0x3,	0x4,	8x3,	8x4
211	(0x8) x (3x5)	0x3,	0x5,	8x3,	8x5
212	(0x8) x (3x6)	0x3,	0x6,	8x3,	8x6
213	(0x8) x (3x7)	0x3,	0x7,	8x3,	8x7
214	(0x8) x (3x9)	0x3,	0x9,	8x3,	8x9
215	(0x8) x (4x5)	0x4,	0x5,	8x4,	8x5
216	(0x8) x (4x6)	0x4,	0x6,	8x4,	8x6
217	(0x8) x (4x7)	0x4,	0x7,	8x4,	8x7
218	(0x8) x (4x9)	0x4,	0x9,	8x4,	8x9
219	(0x8) x (5x6)	0x5,	0x6,	8x5,	8x6
220	(0x8) x (5x7)	0x5,	0x7,	8x5,	8x7
221	(0x8) x (5x9)	0x5,	0x9,	8x5,	8x9
222	(0x8) x (6x7)	0x6	0x7,	8x6,	8x7
223	(0x8) x (6x9)	0x6,	0x9,	8x6,	8x9
224	(0x8) x (7x9)	0x7,	0x9,	8x7,	8x9
225	(0x9) x (1x2)	0x1,	0x2,	9x1,	9x2
226	(0x9) x (1x3)	0x1,	0x3,	9x1,	9x3
227	(0x9) x (1x4)	0x1,	0x4,	9x1,	9x4
228	(0x9) x (1x5)	0x1,	0x5,	9x1,	9x5
229	(0x9) x (1x6)	0x1,	0x6,	9x1,	9x6
230	(0x9) x (1x7)	0x1,	0x7,	9x1,	9x7
231	(0x9) x (1x8)	0x1,	0x8,	9x1,	9x8
232	(0x9) x (2x3)	0x2,	0x3,	9x2,	9x3
233	(0x9) x (2x4)	0x2,	0x4,	9x2,	9x4
234	(0x9) x (2x5)	0x2,	0x5,	9x2,	9x5
235	(0x9) x (2x6)	0x2,	0x6,	9x2,	9x6
236	(0x9) x (2x7)	0x2,	0x7,	9x2,	9x7
237	(0x9) x (2x8)	0x2,	0x8,	9x2,	9x8
238	(0x9) x (3x4)	0x3,	0x4,	9x3,	9x4
239	(0x9) x (3x5)	0x3,	0x5,	9x3,	9x5
240	(0x9) x (3x6)	0x3,	0x6,	9x3,	9x6

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS (*continued*)

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
241	(0x9) x (3x7)	0x3,	0x7,	9x3,	9x7
242	(0x9) x (3x8)	0x3,	0x8,	9x3,	9x8
243	(0x9) x (4x5)	0x4,	0x5,	9x4,	9x5
244	(0x9) x (4x6)	0x4,	0x6,	9x4	9x6
245	(0x9) x (4x7)	0x4,	0x7,	9x4,	9x7
246	(0x9) x (4x8)	0x4,	0x8,	9x4,	9x8
247	(0x9) x (5x6)	0x5,	0x6,	9x5,	9x6
248	(0x9) x (5x7)	0x5,	0x7,	9x5,	9x7
249	(0x9) x (5x8)	0x5,	0x8,	9x5,	9x8
250	(0x9) x (6x7)	0x6,	0x7,	9x6,	9x7
251	(0x9) x (6x8)	0x6,	0x8,	9x6,	9x8
252	(0x9) x (7x8)	0x7,	0x8,	9x7,	9x8
253	(1x2) x (3x4)	1x3,	1x4,	2x3,	2x4
254	(1x2) x (3x5)	1x3,	1x5,	2x3,	2x5
255	(1x2) x (3x6)	1x3,	1x6,	2x3,	2x6
256	(1x2) x (3x7)	1x3,	1x7,	2x3,	2x7
257	(1x2) x (3x8)	1x3,	1x8,	2x3,	2x8
258	(1x2) x (3x9)	1x3,	1x9,	2x3,	2x9
259	(1x2) x (4x5)	1x4,	1x5,	2x4,	2x5
260	(1x2) x (4x6)	1x4,	1x6,	2x4,	2x6
261	(1x2) x (4x7)	1x4,	1x7,	2x4,	2x7
262	(1x2) x (4x8)	1x4,	1x8,	2x4,	2x8
263	(1x2) x (4x9)	1x4,	1x9,	2x4,	2x9
264	(1x2) x (5x6)	1x5,	1x6,	2x5,	2x6
265	(1x2) x (5x7)	1x5,	1x7,	2x5.	2x7
266	(1x2) x (5x8)	1x5,	1x8,	2x5,	2x8
267	(1x2) x (5x9)	1x5,	1x9,	2x5,	2x9
268	(1x2) x (6x7)	1x6,	1x7,	2x6,	2x7
269	(1x2) x (6x8)	1x6,	1x8,	2x6,	2x8
270	(1x2) x (6x9)	1x6,	1x9,	2x6,	2x9
271	(1x2) x (7x8)	1x7,	1x8,	2x7,	2x8
272	(1x2) x (7x9)	1x7,	1x9,	2x7,	2x9
273	(1x2) x (8x9)	1x8,	1x9,	2x8,	2x9
274	(1x3) x (2x4)	1x2,	1x4,	3x2,	3x4
275	(1x3) x (2x5)	1x2,	1x5.	3x2,	3x5
276	(1x3) x (2x6)	1x2,	1x6,	3x2,	3x6
277	(1x3) x (2x7)	1x2,	1x7,	3x2,	3x7
278	(1x3) x (2x8)	1x2,	1x8,	3x2,	3x8
279	(1x3) x (2x9)	1x2,	1x9,	3x2,	3x9
280	(1x3) x (4x5)	1x4,	1x5,	3x4,	3x5
281	(1x3) x (4x6)	1x4,	1x6,	3x4,	3x6
282	(1x3) x (4x7)	1x4,	1x7,	3x4,	3x7
283	(1x3) x (4x8)	1x4,	1x8,	3x4,	3x8
284	(1x3) x (4x9)	1x4,	1x9,	3x4,	3x9
285	(1x3) x (5x6)	1x5,	1x6,	3x5,	3x6
286	(1x3) x (5x7)	1x5,	1x7,	3x5,	3x7
287	(1x3) x (5x8)	1x5,	1x8,	3x5.	3x8
288	(1x3) x (5x9)	1x5,	1x9,	3x5,	3x9
289	(1x3) x (6x7)	1x6,	1x7,	3x6,	3x7
290	(1x3) x (6x8)	1x6,	1x8,	3x6,	3x8
291	(1x3) x (6x9)	1x6,	1x9,	3x6,	3x9
292	(1x3) x (7x8)	1x7,	1x8,	3x7,	3x8
293	(1x3) x (7x9)	1x7,	1x9,	3x7,	3x9
294	(1x3) x (8x9)	1x8,	1x9,	3x8,	3x9
295	(1x4) x (2x3)	1x2,	1x3,	4x2,	4x3
296	(1x4) x (2x5)	1x2,	1x5,	4x2,	4x5
297	(1x4) x (2x6)	1x2,	1x6,	4x2,	4x6
298	(1x4) x (2x7)	1x2,	1x7,	4x2,	4x7
299	(1x4) x (2x8)	1x2,	1x8,	4x2,	4x8
300	(1x4) x (2x9)	1x2,	1x9,	4x2,	4x9

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS *(continued)*

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
301	(1x4) x (3x5)	1x3,	1x5,	4x3,	4x5
302	(1x4) x (3x6)	1x3,	1x6,	4x3,	4x6
303	(1x4) x (3x7)	1x3,	1x7,	4x3,	4x7
304	(1x4) x (3x8)	1x3,	1x8,	4x3,	4x8
305	(1x4) x (3x9)	1x3,	1x9,	4x3,	4x9
306	(1x4) x (5x6)	1x5,	1x6,	4x5,	4x6
307	(1x4) x (5x7)	1x5,	1x7,	4x5,	4x7
308	(1x4) x (5x8)	1x5,	1x8,	4x5,	4x8
309	(1x4) x (5x9)	1x5,	1x9,	4x5,	4x9
310	(1x4) x (6x7)	1x6,	1x7,	4x6,	4x7
311	(1x4) x (6x8)	1x6,	1x8,	4x6,	4x8
312	(1x4) x (6x9)	1x6,	1x9,	4x6,	4x9
313	(1x4) x (7x8)	1x7,	1x8,	4x7,	4x8
314	(1x4) x (7x9)	1x7,	1x9,	4x7,	4x9
315	(1x4) x (8x9)	1x8,	1x9,	4x8,	4x9
316	(1x5) x (2x3)	1x2,	1x3,	5x2,	5x3
317	(1x5) x (2x4)	1x2,	1x4,	5x2,	5x4
318	(1x5) x (2x6)	1x2,	1x6,	5x2,	5x6
319	(1x5) x (2x7)	1x2,	1x7,	5x2,	5x7
320	(1x5) x (2x8)	1x2,	1x8,	5x2,	5x8
321	(1x5) x (2x9)	1x2,	1x9,	5x2,	5x9
322	(1x5) x (3x4)	1x3,	1x4,	5x3,	5x4
323	(1x5) x (3x6)	1x3,	1x6,	5x3,	5x6
324	(1x5) x (3x7)	1x3,	1x7,	5x3,	5x7
325	(1x5) x (3x8)	1x3,	1x8,	5x3,	5x8
326	(1x5) x (3x9)	1x3,	1x9,	5x3,	5x9
327	(1x5) x (4x6)	1x4,	1x6,	5x4,	5x6
328	(1x5) x (4x7)	1x4,	1x7,	5x4,	5x7
329	(1x5) x (4x8)	1x4,	1x8,	5x4,	5x8
330	(1x5) x (4x9)	1x4,	1x9,	5x4,	5x9
331	(1x5) x (6x7)	1x6,	1x7,	5x6,	5x7
332	(1x5) x (6x8)	1x6,	1x8,	5x6,	5x8
333	(1x5) x (6x9)	1x6,	1x9,	5x6,	5x9
334	(1x5) x (7x8)	1x7,	1x8,	5x7,	5x8
335	(1x5) x (7x9)	1x7,	1x9,	5x7,	5x9
336	(1x5) x (8x9)	1x8,	1x9,	5x8,	5x9
337	(1x6) x (2x3)	1x2,	1x3,	6x2,	6x3
338	(1x6) x (2x4)	1x2,	1x4,	6x2,	6x4
339	(1x6) x (2x5)	1x2,	1x5,	6x2,	6x5
340	(1x6) x (2x7)	1x2,	1x7,	6x2,	6x7
341	(1x6) x (2x8)	1x2,	1x8,	6x2,	6x8
342	(1x6) x (2x9)	1x2,	1x9,	6x2,	6x9
343	(1x6) x (3x4)	1x3,	1x4,	6x3,	6x4
344	(1x6) x (3x5)	1x3,	1x5,	6x3,	6x5
345	(1x6) x (3x7)	1x3,	1x7,	6x3,	6x7
346	(1x6) x (3x8)	1x3,	1x8,	6x3,	6x8
347	(1x6) x (3x9)	1x3,	1x9,	6x3,	6x9
348	(1x6) x (4x5)	1x4,	1x5,	6x4,	6x5
349	(1x6) x (4x7)	1x4,	1x7,	6x4,	6x7
350	(1x6) x (4x8)	1x4,	1x8,	6x4,	6x8
351	(1x6) x (4x9)	1x4,	1x9,	6x4,	6x9
352	(1x6) x (5x7)	1x5,	1x7,	6x5,	6x7
353	(1x6) x (5x8)	1x5,	1x8,	6x5,	6x8
354	(1x6) x (5x9)	1x5,	1x9,	6x5,	6x9
355	(1x6) x (7x8)	1x7,	1x8,	6x7,	6x8
356	(1x6) x (7x9)	1x7,	1x9,	6x7,	6x9
357	(1x6) x (8x9)	1x8,	1x9,	6x8,	6x9
358	(1x7) x (2x3)	1x2,	1x3,	7x2,	7x3
359	(1x7) x (2x4)	1x2,	1x4,	7x2,	7x4
360	(1x7) x (2x5)	1x2,	1x5,	7x2,	7x5

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS (*continued*)

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
361	(1x7) x (2x6)	1x2,	1x6,	7x2,	7x6
362	(1x7) x (2x8)	1x2,	1x8,	7x2,	7x8
363	(1x7) x (2x9)	1x2,	1x9,	7x2,	7x9
364	(1x7) x (3x4)	1x3,	1x4,	7x3,	7x4
365	(1x7) x (3x5)	1x3,	1x5,	7x3,	7x5
366	(1x7) x (3x6)	1x3,	1x6,	7x3,	7x6
367	(1x7) x (3x8)	1x3,	1x8,	7x3,	7x8
368	(1x7) x (3x9)	1x3,	1x9,	7x3,	7x9
369	(1x7) x (4x5)	1x4,	1x5,	7x4,	7x5
370	(1x7) x (4x6)	1x4,	1x6,	7x4,	7x6
371	(1x7) x (4x8)	1x4,	1x8,	7x4,	7x8
372	(1x7) x (4x9)	1x4,	1x9,	7x4,	7x9
373	(1x7) x (5x6)	1x5,	1x6,	7x5,	7x6
374	(1x7) x (5x8)	1x5,	1x8,	7x5,	7x8
375	(1x7) x (5x9)	1x5,	1x9,	7x5,	7x9
376	(1x7) x (6x8)	1x6,	1x8,	7x6,	7x8
377	(1x7) x (6x9)	1x6,	1x9,	7x6,	7x9
378	(1x7) x (8x9)	1x8,	1x9,	7x8,	7x9
379	(1x8) x (2x3)	1x2,	1x3,	8x2,	8x3
380	(1x8) x (2x4)	1x2,	1x4,	8x2,	8x4
381	(1x8) x (2x5)	1x2,	1x5,	8x2,	8x5
382	(1x8) x (2x6)	1x2,	1x6,	8x2,	8x6
383	(1x8) x)2x7)	1x2,	1x7,	8x2,	8x7
384	(1x8) x (2x9)	1x2,	1x9,	8x2,	8x9
385	(1x8) x (3x4)	1x3,	1x4,	8x3,	8x4
386	(1x8) x (3x5)	1x3,	1x5,	8x3,	8x5
387	(1x8) x (3x6)	1x3,	1x6,	8x3,	8x6
388	(1x8) x (3x7)	1x3,	1x7,	8x3,	8x7
389	(1x8) x (3x9)	1x3,	1x9,	8x3,	8x9
390	(1x8) x (4x5)	1x4,	1x5,	8x4,	8x5
391	(1x8) x (4x6)	1x4,	1x6,	8x4,	8x6
392	(1x8) x (4x7)	1x4,	1x7,	8x4,	8x7
393	(1x8) x (4x9)	1x4,	1x9,	8x4,	8x9
394	(1x8) x (5x6)	1x5,	1x6,	8x5,	8x6
395	(1x8) x (5x7)	1x5,	1x7,	8x5,	8x7
396	(1x8) x (5x9)	1x5,	1x9,	8x5,	8x9
397	(1x8) x (6x7)	1x6,	1x7,	8x6,	8x7
398	(1x8) x (6x9)	1x6,	1x9,	8x6,	8x9
399	(1x8) x (7x9)	1x7,	1x9,	8x7,	8x9
400	(1x9) x (2x3)	1x2,	1x3,	9x2,	9x3
401	(1x9) x (2x4)	1x2,	1x4,	9x2,	9x4
402	(1x9) x (2x5)	1x2,	1x5,	9x2,	9x5
403	(1x9) x (2x6)	1x2,	1x6,	9x2,	9x6
404	(1x9) x (2x7)	1x2,	1x7,	9x2,	9x7
405	(1x9) x (2x8)	1x2,	1x8,	9x2,	9x8
406	(1x9) x (3x4)	1x3,	1x4,	9x3,	9x4
407	(1x9) x (3x5)	1x3,	1x5,	9x3,	9x5
408	(1x9) x (3x6)	1x3,	1x6,	9x3,	9x6
409	(1x9) x (3x7)	1x3,	1x7,	9x3,	9x7
410	(1x9) x (3x8)	1x3,	1x8,	9x3,	9x8
411	(1x9) x (4x5)	1x4,	1x5,	9x4,	9x5
412	(1x9) x (4x6)	1x4,	1x6,	9x4,	9x6
413	(1x9) x (4x7)	1x4,	1x7,	9x4,	9x7
414	(1x9) x (4x8)	1x4,	1x8,	9x4,	9x8
415	(1x9) x (5x6)	1x5,	1x6,	9x5,	9x6
416	(1x9) x (5x7)	1x5,	1x7,	9x5,	9x7
417	(1x9) x (5x8)	1x5,	1x8,	9x5,	9x8
418	(1x9) x (6x7)	1x6,	1x7,	9x6,	9x7
419	(1x9) x (6x8)	1x6,	1x8,	9x6,	9x8
420	(1x9) x (7x8)	1x7,	1x8,	9x7,	9x8

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS (*continued*)

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
421	(2x3) x (4x5)	2x4,	2x5,	3x4,	3x5
422	(2x3) x (4x6)	2x4,	2x6,	3x4,	3x6
423	(2x3) x (4x7)	2x4,	2x7,	3x4,	3x7
424	(2x3) x (4x8)	2x4,	2x8,	3x4,	3x8
425	(2x3) x (4x9)	2x4,	2x9,	3x4,	3x9
426	(2x3) x (5x6)	2x5,	2x6,	3x5,	3x6
427	(2x3) x (5x7)	2x5,	2x7,	3x5,	3x7
428	(2x3) x (5x8)	2x5,	2x8,	3x5,	3x8
429	(2x3) x (5x9)	2x5,	2x9,	3x5,	3x9
430	(2x3) x (6x7)	2x6,	2x7,	3x6,	3x7
431	(2x3) x (6x8)	2x6,	2x8,	3x6,	3x8
432	(2x3) x (6x9)	2x6,	2x9,	3x6,	3x9
433	(2x3) x (7x8)	2x7,	2x8,	3x7,	3x8
434	(2x3) x (7x9)	2x7,	2x9,	3x7,	3x9
435	(2x3) x (8x9)	2x8,	2x9,	3x8,	3x9
436	(2x4) x (3x5)	2x3,	2x5,	4x3,	4x5
437	(2x4) x (3x6)	2x3,	2x6,	4x3,	4x6
438	(2x4) x (3x7)	2x3,	2x7,	4x3,	4x7
439	(2x4) x (3x8)	2x3,	2x8,	4x3,	4x8
440	(2x4) x (3x9)	2x3,	2x9,	4x3,	4x9
441	(2x4) x (5x6)	2x5,	2x6,	4x5,	4x6
442	(2x4) x (5x7)	2x5,	2x7,	4x5,	4x7
443	(2x4) x (5x8)	2x5,	2x8,	4x5,	4x8
444	(2x4) x (5x9)	2x5,	2x9,	4x5,	4x9
445	(2x4) x (6x7)	2x6,	2x7,	4x6,	4x7
446	(2x4) x (6x8)	2x6,	2x8,	4x6,	4x8
447	(2x4) x (6x9)	2x6,	2x9,	4x6,	4x9
448	(2x4) x (7x8)	2x7,	2x8,	4x7,	4x8
449	(2x4) x (7x9)	2x7,	2x9,	4x7,	4x9
450	(2x4) x (8x9)	2x8,	2x9,	4x8,	4x9
451	(2x5) x (3x4)	2x3,	2x4,	5x3,	5x4
452	(2x5) x (3x6)	2x3,	2x6,	5x3,	5x6
453	(2x5) x (3x7)	2x3,	2x7,	5x3,	5x7
454	(2x5) x (3x8)	2x3,	2x8,	5x3,	5x8
455	(2x5) x (3x9)	2x3,	2x9,	5x3,	5x9
456	(2x5) x (4x6)	2x4,	2x6,	5x4,	5x6
457	(2x5) x (4x7)	2x4,	2x7,	5x4,	5x7
458	(2x5) x (4x8)	2x4,	2x8,	5x4,	5x8
459	(2x5) x (4x9)	2x4,	2x9,	5x4,	5x9
460	(2x5) x (6x7)	2x6,	2x7,	5x6,	5x7
461	(2x5) x (6x8)	2x6,	2x8,	5x6,	5x8
462	(2x5) x (6x9)	2x6,	2x9,	5x6,	5x9
463	(2x5) x (7x8)	2x7,	2x8,	5x7,	5x8
464	(2x5) x (7x9)	2x7,	2x9,	5x7,	5x9
465	(2x5) x (8x9)	2x8,	2x9,	5x8,	5x9
466	(2x6) x (3x4)	2x3,	2x4,	6x3,	6x4
467	(2x6) x (3x5)	2x3,	2x5,	6x3,	6x5
468	(2x6) x (3x7)	2x3,	2x7,	6x3,	6x7
469	(2x6) x (3x8)	2x3,	2x8,	6x3,	6x8
470	(2x6) x (3x9)	2x3,	2x9,	6x3,	6x9
471	(2x6) x (4x5)	2x4,	2x5,	6x4,	6x5
472	(2x6) x (4x7)	2x4,	2x7,	6x4,	6x7
473	(2x6) x (4x8)	2x4,	2x8,	6x4,	6x8
474	(2x6) x (4x9)	2x4,	2x9,	6x4,	6x9
475	(2x6) x (5x7)	2x5,	2x7,	6x5,	6x7
476	(2x6) x (5x8)	2x5,	2x8,	6x5,	6x8
477	(2x6) x (5x9)	2x5,	2x9,	6x5,	6x9
478	(2x6) x (7x8)	2x7,	2x8,	6x7,	6x8
479	(2x6) x (7x9)	2x7,	2x9,	6x7,	6x9
480	(2x6) x (8x9)	2x8,	2x9,	6x8,	6x9

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS (*continued*)

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
481	(2x7) x (3x4)	2x3,	2x4,	7x3,	7x4
482	(2x7) x (3x5)	2x3,	2x5,	7x3,	7x5
483	(2x7) x (3x6)	2x3,	2x6,	7x3,	7x6
484	(2x7) x (3x8)	2x3,	2x8,	7x3,	7x8
485	(2x7) x (3x9)	2x3,	2x9,	7x3,	7x9
486	(2x7) x (4x5)	2x4,	2x5,	7x4,	7x5
487	(2x7) x (4x6)	2x4,	2x6,	7x4,	7x6
488	(2x7) x (4x8)	2x4,	2x8,	7x4,	7x8
489	(2x7) x (4x9)	2x4,	2x9,	7x4,	7x9
490	(2x7) x (5x6)	2x5,	2x6,	7x5,	7x6
491	(2x7) x (5x8)	2x5,	2x8,	7x5,	7x8
492	(2x7) x (5x9)	2x5,	2x9,	7x5,	7x9
493	(2x7) x (6x8)	2x6,	2x8,	7x6,	7x8
494	(2x7) x (6x9)	2x6,	2x9,	7x6,	7x9
495	(2x7) x (8x9)	2x8,	2x9,	7x8,	7x9
496	(2x8) x (3x4)	2x3,	2x4,	8x3,	8x4
497	(2x8) x (3x5)	2x3,	2x5,	8x3,	8x5
498	(2x8) x (3x6)	2x3,	2x6,	8x3,	8x6
499	(2x8) x (3x7)	2x3,	2x7,	8x3,	8x7
500	(2x8) x (3x9)	2x3,	2x9,	8x3,	8x9
501	(2x8) x (4x5)	2x4,	2x5,	8x4,	8x5
502	(2x8) x (4x6)	2x4,	2x6,	8x4,	8x6
503	(2x8) x (4x7)	2x4,	2x7,	8x4,	8x7
504	(2x8) x (4x9)	2x4,	2x9,	8x4,	8x9
505	(2x8) x (5x6)	2x5,	2x6,	8x5,	8x6
506	(2x8) x (5x7)	2x5,	2x7,	8x5,	8x7
507	(2x8) x (5x9)	2x5,	2x9,	8x5,	8x9
508	(2x8) x (6x7)	2x6,	2x7,	8x6,	8x7
509	(2x8) x (6x9)	2x6,	2x9,	8x6,	8x9
510	(2x8) x (7x9)	2x7,	2x9,	8x7,	8x9
511	(2x9) x (3x4)	2x3,	2x4,	9x3,	9x4
512	(2x9) x (3x5)	2x3,	2x5,	9x3,	9x5
513	(2x9) x (3x6)	2x3,	2x6,	9x3,	9x6
514	(2x9) x (3x7)	2x3,	2x7,	9x3,	9x7
515	(2x9) x (3x8)	2x3,	2x8,	9x3,	9x8
516	(2x9) x (4x5)	2x4,	2x5,	9x4,	9x5
517	(2x9) x (4x6)	2x4,	2x6,	9x4,	9x6
518	(2x9) x (4x7)	2x4,	2x7,	9x4,	9x7
519	(2x9) x (4x8)	2x4,	2x8,	9x4,	9x8
520	(2x9) x (5x6)	2x5,	2x6,	9x5,	9x6
521	(2x9) x (5x7)	2x5,	2x7,	9x5,	9x7
522	(2x9) x (5x8)	2x5,	2x8,	9x5,	9x8
523	(2x9) x (6x7)	2x6,	2x7,	9x6,	9x7
524	(2x9) x (6x8)	2x6,	2x8,	9x6,	9x8
525	(2x9) x (7x8)	2x7,	2x8,	9x7,	9x8
526	(3x4) x (5x6)	3x5,	3x6,	4x5,	4x6
527	(3x4) x (5x7)	3x5,	3x7,	4x5,	4x7
528	(3x4) x (5x8)	3x5,	3x8,	4x5,	4x8
529	(3x4) x (5x9)	3x5,	3x9,	4x5,	4x9
530	(3x4) x (6x7)	3x6,	3x7,	4x6,	4x7
531	(3x4) x (6x8)	3x6,	3x8,	4x6,	4x8
532	(3x4) x (6x9)	3x6,	3x9,	4x6,	4x9
533	(3x4) x (7x8)	3x7,	3x8,	4x7,	4x8
534	(3x4) x (7x9)	3x7,	3x9,	4x7,	4x9
535	(3x4) x (8x9)	3x8,	3x9,	4x8,	4x9
536	(3x5) x (4x6)	3x4,	3x6,	5x4,	5x6
537	(3x5) x (4x7)	3x4,	3x7,	5x4,	5x7
538	(3x5) x (4x8)	3x4,	3x8,	5x4,	5x8
539	(3x5) x (4x9)	3x4,	3x9,	5x4,	5x9
540	(3x5) x (6x7)	3x6,	3x7,	5x6,	5x7

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS (*continued*)

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
541	(3x5) x (6x8)	3x6,	3x8,	5x6,	5x8
542	(3x5) x (6x9)	3x6,	3x9,	5x6,	5x9
543	(3x5) x (7x8)	3x7,	3x8,	5x7,	5x8
544	(3x5) x (7x9)	3x7,	3x9	5x7,	5x9
545	(3x5) x (8x9)	3x8,	3x9,	5x8,	5x9
546	(3x6) x (4x5)	3x4,	3x5,	6x4,	6x5
547	(3x6) x (4x7)	3x4,	3x7,	6x4,	6x7
548	(3x6) x (4x8)	3x4,	3x8,	6x4,	6x8
549	(3x6) x (4x9)	3x4,	3x9,	6x4,	6x9
550	(3x6) x (5x7)	3x5,	3x7,	6x5,	6x7
551	(3x6) x (5x8)	3x5,	3x8	6x5,	6x8
552	(3x6) x (5x9)	3x5,	3x9,	6x5,	6x9
553	(3x6) x (7x8)	3x7,	3x8	6x7,	6x8
554	(3x6) x (7x9)	3x7,	3x9,	6x7,	6x9
555	(3x6) x (8x9)	3x8,	3x9,	6x8,	6x9
556	(3x7) x (4x5)	3x4,	3x5,	7x4,	7x5
557	(3x7) x (4x6)	3x4,	3x6,	7x4,	7x6
558	(3x7) x (4x8)	3x4,	3x8,	7x4,	7x8
559	(3x7) x (4x9)	3x4,	3x9,	7x4,	7x9
560	(3x7) x (5x6)	3x5,	3x6,	7x5,	7x6
561	(3x7) x (5x8)	3x5,	3x8,	7x5,	7x8
562	(3x7) x (5x9)	3x5,	3x9,	7x5,	7x9
563	(3x7) x (6x8)	3x6,	3x8,	7x6,	7x8
564	(3x7) x (6x9)	3x6,	3x9,	7x6,	7x9
565	(3x7) x (8x9)	3x8,	3x9,	7x8,	7x9
566	(3x8) x (4x5)	3x4,	3x5,	8x4,	8x5
567	(3x8) x (4x6)	3x4,	3x6,	8x4,	8x6
568	(3x8) x (4x7)	3x4,	3x7,	8x4,	8x7
569	(3x8) x (4x9)	3x4,	3x9,	8x4,	8x9
570	(3x8) x (5x6)	3x5,	3x6,	8x5,	8x6
571	(3x8) x (5x7)	3x5,	3x7,	8x5,	8x7
572	(3x8) x (5x9)	3x5,	3x9,	8x5,	8x9
573	(3x8) x (6x7)	3x6,	3x7,	8x6,	8x7
574	(3x8) x (6x9)	3x6,	3x9,	8x6,	8x9
575	(3x8) x (7x9)	3x7.	3x9,	8x7,	8x9
576	(3x9) x (4x5)	3x4,	3x5,	9x4,	9x5
577	(3x9) x (4x6)	3x4,	3x6,	9x4,	9x6
578	(3x9) x (4x7)	3x4,	3x7,	9x4,	9x7
579	(3x9) x (4x8)	3x4,	3x8,	9x4,	9x8
580	(3x9) x (5x6)	3x5,	3x6,	9x5,	9x6
581	(3x9) x (5x7)	3x5,	3x7,	9x5,	9x7
582	(3x9) x (5x8)	3x5,	3x8,	9x5,	9x8
583	(3x9) x (6x7)	3x6,	3x7,	9x6,	9x7
584	(3x9) x (6x8)	3x6,	3x8,	9x6,	9x8
585	(3x9) x (7x8)	3x7,	3x8,	9x7,	9x8
586	(4x5) x (6x7)	4x6,	4x7,	5x6,	5x7
587	(4x5) x (6x8)	4x6,	4x8,	5x6,	5x8
588	(4x5) x (6x9)	4x6,	4x9,	5x6,	5x9
589	(4x5) x (7x8)	4x7,	4x8,	5x7,	5x8
590	(4x5) x (7x9)	4x7,	4x9,	5x7,	5x9
591	(4x5) x (8x9)	4x8,	4x9,	5x8,	5x9
592	(4x6) x (5x7)	4x5,	4x7,	6x5,	6x7
593	(4x6) x (5x8)	4x5,	4x8,	6x5,	6x8
594	(4x6) x (5x9)	4x5,	4x9,	6x5,	6x9
595	(4x6) x (7x8)	4x7,	4x8,	6x7,	6x8
596	(4x6) x (7x9)	4x7,	4x9,	6x7,	6x9
597	(4x6) x (8x9)	4x8,	4x9,	6x8,	6x9
598	(4x7) x (5x6)	4x5,	4x6,	7x5,	7x6
599	(4x7) x (5x8)	4x5,	4x8,	7x5,	7x8
600	(4x7) x (5x9)	4x5,	4x9,	7x5,	7x9

TABLE VI. — CODE NUMBERS FOR PREDICTING THE PERFORMANCE OF DOUBLE-CROSS HYBRIDS (*concluded*)

Hybrid no.	Pedigree of predicted double cross	Code of nonparental single crosses for prediction			
601	(4x7) x (6x8)	4x6,	4x8,	7x6,	7x8
602	(4x7) x (6x9)	4x6,	4x9,	7x6,	7x9
603	(4x7) x (8x9)	4x8,	4x9,	7x8,	7x9
604	(4x8) x (5x6)	4x5,	4x6,	8x5,	8x6
605	(4x8) x (5x7)	4x5,	4x7,	8x5,	8x7
606	(4x8) x (5x9)	4x5,	4x9,	8x5,	8x9
607	(4x8) x (6x7)	4x6,	4x7,	8x6,	8x7
608	(4x8) x (6x9)	4x6,	4x9,	8x6,	8x9
609	(4x8) x (7x9)	4x7,	4x9,	8x7,	8x9
610	(4x9) x (5x6)	4x5,	4x6,	9x5,	9x6
611	(4x9) x (5x7)	4x5,	4x7,	9x5,	9x7
612	(4x9) x (5x8)	4x5,	4x8,	9x5,	9x8
613	(4x9) x (6x7)	4x6,	4x7,	9x6,	9x7
614	(4x9) x (6x8)	4x6,	4x8,	9x6,	9x8
615	(4x9) x (7x8)	4x7,	4x8,	9x7,	9x8
616	(5x6) x (7x8)	5x7,	5x8,	6x7,	6x8
617	(5x6) x (7x9)	5x7,	5x9,	6x7,	6x9
618	(5x6) x (8x9)	5x8,	5x9,	6x8	6x9
619	(5x7) x (6x8)	5x6,	5x8,	7x6,	7x8
620	(5x7) x (6x9)	5x6,	5x9,	7x6,	7x9
621	(5x7) x (8x9)	5x8,	5x9,	7x8,	7x9
622	(5x8) x (6x7)	5x6,	5x7,	8x6,	8x7
623	(5x8) x (6x9)	5x6,	5x9,	8x6,	8x9
624	(5x8) x (7x9)	5x7,	5x9,	8x7,	8x9
625	(5x9) x (6x7)	5x6,	5x7,	9x6,	9x7
626	(5x9) x (6x8)	5x6,	5x8,	9x6,	9x8
627	(5x9) x (7x8)	5x7,	5x8,	9x7,	9x8
628	(6x7) x (8x9)	6x8,	6x9,	7x8,	7x9
629	(6x8) x (7x9)	6x7,	6x9,	8x7,	8x9
630	(6x9) x (7x8)	6x7,	6x8,	9x7,	9x8

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CONVERSION FACTORS

Area

1 hectare	2.47109 acres
1 square kilometer	0.38610 square mile
1 square kilometer	*100 hectares*
1 acre	0.40468 hectare
1 square mile	2.5900 square kilometers
1 square mile	*645 acres* 259 hectares

Weight

1 kilogram	2.20463 pounds
1 metric ton	0.98420 long ton 1.10231 short tons
1 metric ton	*1,000 kilograms*
1 pound	0.45359 kilograms
1 long ton	1.01605 metric tons
1 short ton	0.90718 metric ton
1 long ton	*2,240 pounds*
1 short ton	*2,000 pounds*

Liquid Measure

1 liter	0.26418 U. S. gallon 0.21997 Imp. gallon
1 hectoliter	*100 liters*
1 U. S. gallon	3.78533 liters
1 Imp. gallon	4.54596 liters
1 gallon	*4 quarts*

Yield

1,000 kilograms per hectare	1.4869 bushels (60 lb.) per acre
1 bushel (60 lb.) per acre	67.253 kilograms per hectare

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